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Smart BMI Scale: Design and Prototyping of an IoT-Enabled Ultrasonic, Load-Cell Device for Early Obesity Self-Diagnosis

HATEGEKIYAREMYE Evariste[1], Mahomet KAZUBWENGE[2]
[1]Center of Excellence in Biomedical Engineering and E-Health (CEBE), College of Science and Technology, University of Rwanda, Kigali, Rwanda
[2]Department of Information Technology, School of Computing, Informatics and Media Studies, Mount Kigali University, Kigali, Rwanda

Abstract—*Obesity is a major driver of non-communicable diseases (NCDs) and rising healthcare costs worldwide, yet routine self-assessment of Body Mass Index (BMI) still depends on clinical visits, manual tape-measure and weighing-scale readings, or smartphone applications that are not accessible to everyone. This paper presents the design, prototyping and validation of a low-cost, stand-alone BMI monitoring device that measures body height and mass directly and computes BMI in real time without manual data entry. The prototype uses an HC-SR04 ultrasonic sensor to measure standing height, a 200 kg-capacity load cell with an HX711 amplifier to measure body mass, and a NodeMCU/Arduino microcontroller to process the two readings, compute BMI and classify the user as underweight, normal or overweight on a 20×4 I2C liquid-crystal display. The system architecture, circuit design, governing equations and firmware logic are described, and the assembled prototype is validated against conventional tape-measure and weighing-scale measurements on five randomly selected test users drawn from a pool of fifty participants at the University of Rwanda, College of Science and Technology. The prototype reproduced weight within 0.30 kg and height within 0.08 m of the reference instruments, and the obesity status it reported matched the manually derived status in every test case. The results show that a simple sensor-fusion approach can deliver an accurate, inexpensive and easy-to-use tool for early, at-home obesity screening.*

Keywords— *Body Mass Index; obesity; load cell; ultrasonic sensor; NodeMCU; self-monitoring; embedded system.*

I. Introduction

Obesity is recognized as one of the most significant risk factors for non-communicable diseases (NCDs) and the healthcare costs associated with them in the twenty-first century [1]. In 2019 alone, obesity-related NCDs were responsible for an estimated five million deaths, corresponding to 12% of all NCD deaths worldwide [2]. According to the World Health Organization, close to two billion adults were overweight in 2016, of whom more than six hundred million were obese; the global prevalence of obesity had tripled since 1975, and, if the trend continued, close to a third of the world's adult population was projected to be overweight by 2025 [3]. In Rwanda, national survey data have shown a similar pattern, with a meaningful share of the adult population overweight or obese and a distinct gender gap in prevalence.

Body Mass Index (BMI), obtained from a person's mass and height, remains the most widely used first-line indicator of obesity because it is inexpensive and simple to compute [4], [5]. In practice, however, individuals rarely track their BMI regularly because doing so still requires a visit to a health facility, or manually measuring height and weight and computing the ratio by hand a process that is time-consuming and prone to error, particularly outside clinical settings. This creates a gap between the availability of a low-cost health metric and its convenient use for continuous self-monitoring.

This paper addresses that gap by presenting a stand-alone, sensor-based BMI monitoring device that automatically measures a user's height and mass and computes and displays the corresponding BMI value and obesity status. The specific objectives of the work were to (i) design a BMI-based monitoring device, (ii) build a working prototype of the design, and (iii) test the prototype's accuracy against conventional measurement instruments. The remainder of the paper is organized as follows: Section II reviews related work; Section III presents the materials, system architecture and governing equations; Section IV describes the prototype implementation; Section V reports the validation results and discussion; and Section VI concludes the paper.

II. Literature Review

Several works have investigated automated or semi-automated approaches to BMI measurement and obesity screening. Karim et al. [6] proposed a portable, IoT-based real-time BMI device that stores current and historical user records and issues nutritional advice based on the computed BMI; the emphasis of that work is on dietary recommendation rather than on stand-alone, on-device diagnosis.

Nanak Zakaria and El Qibthiyah [7] developed a height-and-weight monitoring system using an ultrasonic sensor, a load cell and a NodeMCU ESP8266, similar in sensing principle to the work reported here, but the computed BMI and dietary recommendations were only made available through a companion Android application. This dependence on a smartphone limits accessibility for users who do not own, or are not comfortable operating, a smart device, and adds recurring cost and complexity.

Amani and Amani [8] took a data-driven approach, applying machine-learning classifiers Random Forest, Gaussian Naïve Bayes, Decision Tree, Support Vector Machine, Multi-Layer Perceptron, k-Nearest Neighbors and Logistic Regression to categorize individuals from an existing BMI dataset. While

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informative for population-level classification, such models classify previously collected records rather than perform an independent, real-time measurement of a given individual.

Relative to this body of work, the device presented here differs in three respects: it requires no smartphone application or external dashboard for the primary diagnosis, since height, mass, BMI and obesity status are computed and displayed entirely on-device; it requires no manual entry of body parameters, since both height and mass are sensed directly; and it performs a genuine real-time measurement rather than classifying an existing record.

III. Materials and Methods

A. Data Collection and Sampling

Background information was gathered from journal articles, technical datasheets and prior related studies. For prototype validation, a simple random sample of fifty participants was drawn from the University of Rwanda, College of Science and Technology, Nyarugenge campus. For each participant, height and weight were recorded independently with a tape measure and a weighing scale and were also measured by the prototype, so that the two sets of readings, and the BMI values derived from them, could be compared.

B. System Requirements

The device needed a mass sensor able to support a standing adult of up to 200 kg with repeatable, gram-level precision, and a height sensor able to resolve standing height to within about 3 mm. A microcontroller was required to read both sensors, compute BMI and drive a display, and the mechanical structure needed to hold the sensors rigidly in place so that a user could stand comfortably while being measured.

C. Hardware Component Selection

- Microcontroller: a NodeMCU ESP8266 / Arduino Nano board reads both sensors, executes the BMI calculation and classification logic, drives the display, and can optionally forward readings to a remote server.
- Mass sensor: a 200 kg-capacity load cell paired with an HX711 24-bit load-cell amplifier, which detects small deflections of the load cell, amplifies and digitizes them for the microcontroller [9], [10].
- Height sensor: an HC-SR04 ultrasonic sensor, mounted above the user's head position, measures the round-trip time of a reflected sound pulse to obtain distance, from which standing height is derived [11], [12].
- Display: a 20×4 I2C liquid-crystal display shows the measured weight, height, BMI and obesity status; the I2C interface reduces the number of I/O pins required on the microcontroller [13].
- A push-button switch controls system power to limit heating and power consumption when the device is idle.
- A wooden support structure holds the load cell at the base and the ultrasonic sensor at a fixed height above it, and provides a stable standing platform for the user.

D. System Architecture

Fig. 1 shows the overall block arrangement of the system. The ultrasonic sensor and load cell acquire raw height and mass data respectively; the microcontroller reads, filters and converts these readings, computes BMI, classifies the obesity status and updates the LCD; optionally the record is also pushed to a remote server for later retrieval through a web dashboard.

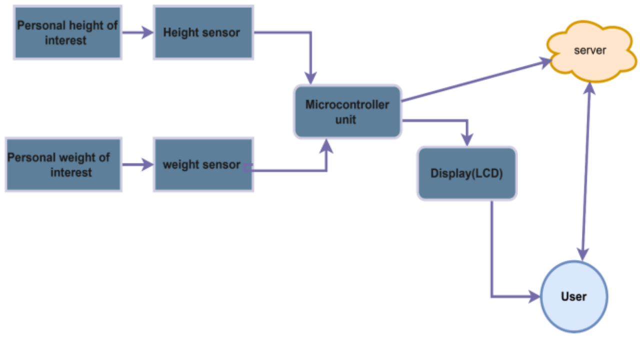

Fig. 1. System block diagram of the BMI monitoring device.

E. Circuit Design

The interconnection of the sensors, amplifier, microcontroller, display and switch was simulated in Fritzing to obtain the circuit diagram shown in Fig. 2, which was then used as the wiring reference during hardware assembly.

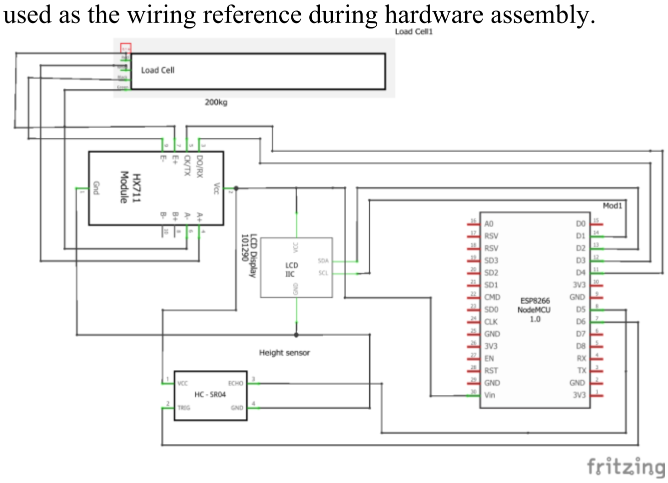

Fig. 2. Circuit diagram of the BMI monitoring prototype.

F. Governing Equations

The ultrasonic sensor determines the distance **d** between itself and the user's head from the round-trip travel time t of the reflected pulse and the speed of sound v (≈ 340 m/s):

$$d = (t \times v) / 2$$

Standing height h is then obtained by subtracting this distance from the fixed reference distance H0 between the sensor and the base of the platform:

$$h = H0 - d$$

The load cell / HX711 stage yields a calibrated body mass m in kilograms after applying the load cell's calibration factor to the raw digitized reading. Body Mass Index is then computed in the standard way [4], [5] as mass divided by the square of height:

$$BMI = m / h^2 \ (kg/m^2)$$

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The computed BMI is compared against the ranges in Table I to obtain the obesity status that is displayed on the LCD alongside the measured mass and height.

TABLE I. BMI classification ranges used by the prototype.

BMI range (kg/m²)	Obesity status
< 18.5	Underweight
18.5 – 24.9	Normal weight
25.0 – 29.9	Overweight

G. System Flow and Firmware

Fig. 3 shows the operating logic implemented in firmware. On start-up the system initializes the display and sensors; in the main loop it triggers the ultrasonic sensor, times the returned echo, reads the load cell, computes height, mass and BMI, selects the matching obesity-status branch, and refreshes the LCD before repeating the cycle. The firmware was written in the Arduino IDE (C/C++), compiled, debugged and uploaded to the microcontroller over USB.

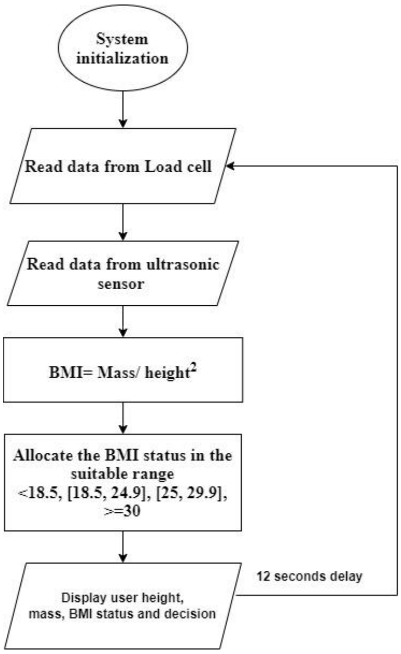

Fig. 3. System flow chart.

IV. Prototype Implementation

The Arduino Nano and HX711 amplifier were mounted together with the power switch on a small board (Fig. 4), the ultrasonic sensor was fixed at the top of the wooden frame, and the load cell was fixed at the base beneath the standing platform (Fig. 5), each wired according to the circuit diagram of Fig. 2.

Assembling the mounted sensors, microcontroller, display and wooden structure produced the complete stand-alone prototype shown in Fig. 6, on which a user stands upright beneath the ultrasonic sensor while the LCD reports the measured parameters.

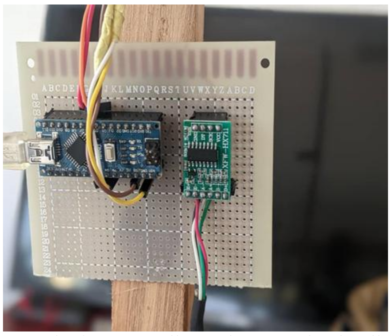

Fig. 4. Mounted microcontroller and HX711 load-cell amplifier.

Fig. 5. Ultrasonic sensor mounted on the frame for height sensing.

Fig. 6. The assembled BMI monitoring prototype (front and side views).

V. Results And Discussion

A. Display Output

Once a user stands on the platform, the LCD reports the measured weight (kg), height (m), computed BMI and obesity status, as illustrated for a normal-weight case in Fig. 7.

B. Validation Against Reference Instruments

Prototype accuracy was verified by comparing its output with manual measurements taken using a tape measure and a weighing scale for five randomly selected test users drawn from

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the fifty-participant sample. Table II summarizes the comparison.

Fig. 7. Prototype display showing weight, height, BMI and a Normal-weight status.

TABLE II. Results observed using weighing scale / tape measure vs. the BMI monitoring prototype.

Test User	Weight - scale (kg)	Weight - prototype (kg)	Height - tape (m)	Height - prototype (m)	BMI (calculated)	BMI (prototype)	Obesity status
1	76.50	76.80	1.66	1.67	27.7	27.8	Overweight
2	58.40	59.42	1.70	1.78	18.9	18.7	Normal weight
3	65.35	65.30	1.76	1.76	21.0	21.0	Normal weight
4	78.98	78.96	1.82	1.82	23.8	23.8	Normal weight
5	65.51	65.53	1.80	1.81	20.2	20.0	Normal weight

Across the five test users, the largest deviation between the prototype and the reference instruments was 0.30 kg for weight and 0.08 m for height. Despite these small deviations, the obesity status reported by the prototype matched the status derived from the manual measurements in every case, indicating that the sensing and classification chain is robust to the small measurement noise introduced by the ultrasonic and load-cell readings. To preserve this level of accuracy and repeatability, users are advised to stand upright and remain still on the platform during measurement, since sensor drift due to motion is the principal source of the observed deviation.

C. Discussion

The results indicate that a two-sensor, single-board design can reproduce manually obtained BMI values closely enough to be useful for everyday self-screening, while removing the two main barriers identified in the reviewed literature: dependence on a companion smartphone application [7] and reliance on previously collected datasets for classification [8]. Because the device reports mass, height, BMI and status directly on an on-board display, it can be used by people without a smartphone or internet access, which is an important consideration for low-resource settings such as rural health posts in Rwanda.

VI. Conclusion And Future Work

This paper presented the design, prototyping and validation of a stand-alone BMI monitoring device that senses body height with an ultrasonic sensor and body mass with a load cell, computes BMI on a NodeMCU/Arduino microcontroller, and displays the result and obesity status on an LCD. Validation against tape-measure and weighing-scale references across five test users showed a maximum deviation of 0.30 kg in weight and 0.08 m in height, with the reported obesity status matching the manual assessment in all cases. As a result, the tool provides an exact, low-cost, and independent device for early self-screening for obesity that does not necessitate manual data entry, a smartphone app, or a clinical visit.

BMI is nonetheless a surrogate measure of body fatness that does not distinguish fat mass from muscle mass, so the prototype should be viewed as a first-line screening aid rather than a diagnostic instrument; clinical validation on larger and more diverse populations is recommended before wider deployment. Future work should explore the integration of the existing remote-server dashboard with telehealth platforms, addition of body-composition sensing, and larger-scale field trials to strengthen the evidence base for public-health use, including within Rwanda's non-communicable-disease prevention programs.

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