International Journal of Biomedical and Clinical Sciences
Vol. 6, No. 3, 2021, pp. 100-119
http://www.aiscience.org/journal/ijbcs

A Low-Cost Automatic Body Mass Index Machine: The Design, Development, Calibration, Testing and Analysis

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Abstract

Body Mass Index (BMI) is a non-invasive method employed to measure the body fat using the individual's weight and height which has a directly relationship with obesity. Obesity is therefore the major public health risk in the world which is associated with a lot of disease such as hypertension, type-2 diabetes mellitus, kidney disease, respiratory problems, degenerative joint disease, and cardiovascular disease. Thus, this paper present the design and development of a low-cost automatic BMI machine for indoor and out-door use. The proposed low-cost automatic BMI machine consists of 7 main sections, namely: *1).* four load-cells connected in Wheatstone bridge configuration with four SR-120 foil-type strain gauges incorporated; *2).* load-cell HX711 amplifier module; *3).* HC-SR04 ultrasonic sensor module; *4).* Internet-ready Arduino Mega 2560 real-time embedded system development board; *5).* an intelligent YJD1602A-1 liquid crystal display (LCD) module; *6).* an automatic two-way backup power supply module; and *7).* a mechanical assembly for enclosing the automatic BMI components. The BMI is computed as the body weight per height squared. The weight measurement is accomplished using the load-cell assembly via the load-cell amplifier module while the height measurement is achieved using the HC-SR04 ultrasonic sensor module. The weight and height measurement modules are interface to the Arduino Mega 2560 development board where the BMI is computed automatically via a computer program embedded in the Arduino Mega 2560 development board and the BMI for an individual is readily displayed on the LCD. The automatic two-way backup power supply module allows the proposed automatic BMI machine to be used for indoor and out-door BMI measurements in the absence and/or presence of public power supply. The proposed automatic BMI machine have been designed, constructed and deployed for automatic BMI measurements and the results have been compared with manual measurements where mean errors of the height, weight, and BMI measurements of 0.0133, 1.8125, and 1.0733 respectively were recorded. The performance of the proposed low-cost automatic BMI machine indicates that it can be used in homes, hospitals, companies as well as in any environments where routine BMI monitoring may be desired.

Keywords

Body Mass Index (BMI), Classification, Electronic Instrumentation, Embedded Systems, Internet-of-Things, Obesity, Risk of Co-Morbidity

Received: September 9, 2019/Accepted: November 12, 2019/Published online: September 26, 2021

1. Introduction

The global epidemic of overweight and obesity is termed "globesity". It is the major public health problem in developed as well as developing world. Recent study conducted among young adults in Nigeria showed that more

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than one in every eight young adults was either overweight or obese [1]. Overweight and obesity accounted for 15-30% of deaths in coronary heart disease and 65-75% of new case of type-2 diabetes mellitus. Overweight and obesity resulted from an energy surplus over the time that is stored in the body as fat [2]. Body mass index (BMI) is the measure of a person's weight in kilograms divided by the square of his/her height in meters. BMI is an approximate measure of overweight or underweight of the body; which is calculated by dividing the weight of the body in kilograms by the square of height in meters. That is:

$$BMI = \frac{weight\ (kg)}{square\ of\ height\ (m^2)} \tag{1}$$

BMI could also be defined as an estimation of the proportion of body weight that is accounted for by fat [3]. It is commonly used as an indicator of obesity which is an attempt to quantify the amount of tissue mass (i.e. muscle, fat, and bone) in an individual and then categorize the person as underweight, normal, overweight or obese based on the value obtained. Other devices used before include skin-fold thicknesses, bioelectrical impedance [4], underwater weighing, dual energy x-ray absorptiometry [5], waist circumference (WC) and waist hip ratio (WHR) [6] in determining overweight and obesity. Similarly, world health organization (WHO) provides general cut off points, in which BMI could be used to classify individuals into four major categories; underweight (< 18.5 kg/m^2), normal (18.5-24.9 kg/m^2), Overweight (25-29.9 kg/m^2), and obese (≥ 30 kg/m^2) [7].

Table 1. Classifications of overweight and obesity in adults.

S/N	Classification	BMI (kg/m^2)	Risk of Co-Morbidities
1.	Underweight	<18.5	Low
2.	Normal range	18.5−24.9	Average
3.	Overweight	25.0−29.9	Increased
4.	Obese class I	30.0−34.9	Moderate
5.	Obese class II	35.0−39.9	Severe
6.	Obese class III	>40	Very severe

Table 2. Percentiles ranking for children and adolescents.

S/N	Percentile Ranking	Weight Status
1.	Less than 5th percentile	Underweight
2.	5th percentile to less than 85th percentile	Healthy weight
3.	85th percentile to less than 95th percentile	Overweight
4.	Equal to or greater than the 95th percentile	Obese

The classifications of overweight and obesity in adults shown in Table 1 according to BMI illustrates the different types of obesity and their respective morbidity [8]. BMI is calculated the same way for Adults and Children, but the results are interpreted differently. For adults, BMI classifications do not depend on age or sex. For children and adolescents between 2 and 20 years old, BMI is interpreted relative to a child's age and sex, because the amount of body fat changes with age and varies by sex. Percentiles are specific to age and sex, classify underweight, healthy weight, overweight, and obesity in children. The BMI-for-age determined for an individual indicates the relative position of the child's BMI value among children of the same sex and age. According to Center for Disease Control and Prevention (CDCP), BMI for age categories and corresponding percentiles are summarized in Table 2 [9]. Furthermore, BMI served as an initial screening for children and adolescents [9].

BMI is very simple, inexpensive, and non-invasive surrogate measure of body fat. BMI could be an approximation for determining potential weight problem but not as a diagnostic tool. Studies have shown that BMI levels correlate with body fat and with future health risks. High BMI predicts future morbidity and death [1–9]. Through BMI measurements, physicians can recommend different health risks related to weight, for example, skin fold measurements, fitness of a person, nutritionist can decide the diet of a person and other screening of person's health.

Medical challenges or decrease in quality of lives of many people is as a result of obesity and sedentary lifestyle [10]. Automatic BMI machine which ought to be an indicator to fat accumulation is usually unavailable for peoples' general use are not easily accessible. The BMI of an individual, according to WHO standard, gives an insight to the health status of an individual malnutrition, normal or over nutrition (obsessed) [7]. The BMI guides medical experts on how to advise their patients on nutrition and health matters. Hitherto, BMI ratio has been manually computed using several means which include paper work and computer software.

Motivated by the above arguments, this work proposes the design and development of a low-cost automatic BMI machine for BMI measurements and monitoring as health indicator of overweight as well as obesity prevalence. The paper is organized as follows. The background knowledge is presented in Section 2. The description, architectures and characteristics of the components for the proposed automatic BMI machine are given in Section 3. Section 4 details the principle of operation, design methodology and hardware-software implementation of the proposed automatic BMI machine while the results and discussions are presented in Section 5. Section 6 concludes the paper with highlights on future direction.

2. Background Knowledge

2.1. Remarks on Overweight and Obesity

Obviously, obesity which broadly refers to excess body fat has become a popular and an important public health problem. Its prevalence continues to increase worldwide. Americans are heavier now than ever before. The prevalence of overweight and obese individuals has increased steadily over the past two decades. For an adult, obesity is defined as having a BMI of 30 kg/m² or higher [11,12]. A study from 2013 showed that almost 40% of adult men and 30% of adult women fall into the overweight category in the United States [13].

Changes in the standard American diet, such as over-consumption and, large portion sizes, along with changes in fitness and activity levels, such as increased sedentary lifestyles, have contributed to the obesity epidemic. There are varieties of influencing factors that are believed to impact obesity such as lifestyle choices, sedentary behaviours, overconsumption, family genetics, nutrition knowledge, stress, environment for physical activities and the food environment [14]. It is generally accepted that being overweight or obese is associated with having higher risks of mortality. However, the evidence must be closely evaluated. The idea that overweight and obese individuals have increased mortality and lives shorter when compared to their normal-weight counterparts may not be merited. Some studies contradicted this idea [13,15]. The question remains, is it necessary to be at a normal weight to be healthy? Due to the increased prevalence of obesity in the United States, more people go on “diets” than ever before. However, these numbers are only increasing as obesity affects more and more Americans. According to one review, several long term studies on men and women indicate that a history of dieting may increase chances for subsequent and significant weight gain [15].

Ironically, cutting calories may perpetuate what dieting is trying to cure (i.e. obesity). This is due to weight fluctuations (typically defined in research studies as a weight loss or gain of more than 5% body weight) and has been associated with a number of adverse health outcomes. When trying to lose weight, one has to ask oneself what is the purpose of trying to lose weight. Losing weight for the sake of aesthetics or improved health is the main reasons individuals’ diet [15]. However, recent research shows that to improve overall health and reduce mortality, reducing body weight might not be the answer for everyone [16].

Obesity is a medical condition in which excess body fat has accumulated to the extent that it may have an adverse effect on health, leading to reduced life expectancy and/or increased health problems [17]. Similarly, obesity can also be defined as an excess of adipose tissue to induce a significant increase in health risks. The instrument currently used to evaluate the relationship between weight and status in both children and adults is the Body Mass Index (BMI) which is calculated by dividing weight (in Kg) by height squared high (in meters). However, recent research has shown that the new BMI for Nigeria is as follows: underweight (less than 17.8kg/m^2), normal weight (17.8 – 24.7kg/m^2), overweight (24.8 – 27.8 kg/m^2) and obesity is (greater than or equal to 27.9 kg/m^2) [1]. By comparing the BMI cut-off point differences between the WHO as shown in Table 1 [7] and Nigeria as given by [1], the average value is found to be +2.1 kg/m^2.

BMI is the metric currently in use for defining anthropometric height/weight characteristics in adults and for classifying (categorizing) them into groups. The common interpretation is that it represents an index of an individual’s fatness. It is widely used as a risk factor for the development of or the prevalence of several health issues [18]. Because BMI in children increases with age and is influenced by pubertal status and sex, for the interpretation of this parameter in children the International Obesity Task Force (IOTF) recommends using reference curves of Cole different in the two sexes. The calculation of the value of BMI at each clinical monitoring is recommended, in case of overweight or obesity, then, to better quantify the fat mass is possible to evaluate the body composition by anthropometric methods (measuring the circumferences of arm, waist and hips and fold cutaneous triceps, biceps, subscapular and suprailiac or methods such as impedance [19].

2.2. Developments in BMI Measurements and Calculations

Height and weight are important indicators of human health. Most people likely know their height up to a certain point. But even, being half an inch to an inch shorter could be a very important indicator to someone’s health. For children, it is important to monitor that they are growing at a healthy rate, and for the elderly it is important to monitor whether or not their height decreases. This could be an indicator of osteoporosis [20].

Presently, height and weight measurement is one of the major aspects of the recruitment process in military, defense and Police force [21]. Thousands of candidates appear for this recruitment process in which the height and weight is measured by traditional method. This process is very clumsy and time consuming. To mitigate this problem, an efficient method is proposed to speed-up the process of height and weight measurement during recruitment processes. In the proposed method by Honade, webcam was used to capture the image of a person, whose height is to be measured [21]. Also, a weight sensor is used for measuring the weight of the person and hence by using height and weight, BMI is calculated to decide the fitness of the person. The drawback of this method is that the mechanism used for weight measurement needs special circuitry having microcontroller, Op-Amp, ADC which can be done using PIC in cost effective way. Doctors commonly use BMI as important indicators for diabetes and heart disease. Currently, methods to measure height and weight are archaic, take too much time, and usually required more than one person. These measurements, especially when directly linked to health, need to be as accurate as possible that should not time consuming. Ultrasonic sensors can provide a solution to this problem.

In the software method, a system application is designed where a graphical user interface (GUI) is made for the user to input a measured height and weight of an individual and press a button that calculates the BMI automatically [22]. The system-based applications, also called BMI calculators, became popular in the early 1990s and was mostly used in specialized hospitals and health offices [22].

Stadiometer is a piece of medical equipment used for measuring human height. It is usually constructed out of a ruler and a sliding horizontal headpiece which is adjusted to rest on the top of the head. Stadiometers are used in routine medical examinations and also clinical tests and experiments [23]. Devices with similar concept, although with higher resolutions, are used in industrial metrology applications, where they are called height gauges. However, a strain gauge-type load cell as a model was proposed and designed for measuring weight [24].

Furthermore, Dipika and co-workers proposed a microcontroller-based automated BMI calculator with LCD display, which calculates the body mass index using the two basic parameters that are weight and height [25]. The hardware of the project consists of a weighing mechanism; i.e. a weighing machine, which is used to calculate the body weight of a person, and a height sensing mechanism which employed the use of light-dependent-resistor (LDR) to calculate the height of a person. The weighing machine increased the cost while inaccuracy resulted from the poor LDR height measurement system.

In a similar way but with slight improvement, Ismail and co-workers designed a microcontroller-based automated BMI calculator with LCD display, which calculates the BMI using the two basic parameters that are weight and height [26]. The hardware of the project consists of a load-cell for body weight measurement while the height measurement was achieved using ultrasonic sensor but with manual computation of the BMI [26].

2.3. Overview of the Proposed Automatic BMI Machine

The block diagram of the proposed low-cost automatic BMI machine is shown in Figure 1. The proposed low-cost automatic BMI machine basically consists of 7 main sections, namely: *1).* MHT1 load-cells arranged in Wheatstone bridge circuit configuration format which incorporates internally mounted SR-120 foil-type strain gauges for weight measurement; *2).* Load-cell HX711 amplifier module which will be used to amplify the milivolt (mV) from the MHT1 load-cell weighing system; *3).* HC-SR04 ultrasonic sensor module which is the main sensor used in this work for height measurement; *4).* Internet-ready Arduino Mega 2560 real-time embedded system development board is the heart of the proposed BMI machine; *5).* An intelligent YJD1602A-1 liquid crystal display (LCD) module where the height, weight and BMI measurements will be displayed; *6).* An automatic two-way backup power supply module supported with a 12 V Li-Po rechargeable batteries; and *7).* A mechanical assembly for enclosing the automatic BMI components. The BMI is computed as the body weight per square height. The weight measurement is accomplished using the MHT1 load-cell assembly via the load-cell amplifier module while the height measurement is achieved using the HC-SR04 ultrasonic sensor module. The weight and height measurement modules are interface to the Arduino Mega 2560 development board where the BMI is computed automatically via a computer program embedded in the Arduino Mega 2560 development board and the BMI for an individual is readily displayed on the LCD together with height and weight measurements. The automatic two-way backup power supply module allows the proposed automatic BMI machine to be used for indoor and out-door BMI measurements in the absence and/or presence of public power supply.

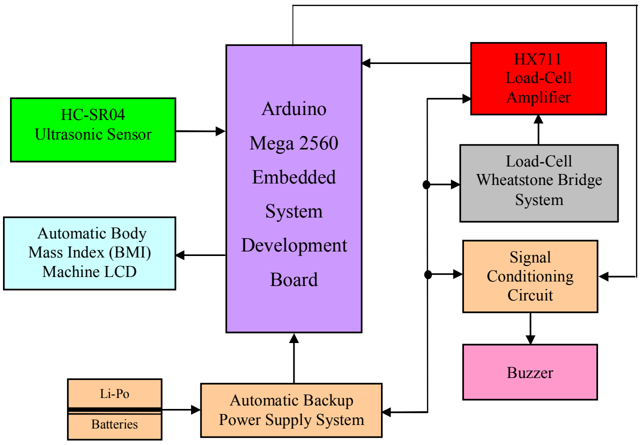


Figure 1. Block diagram of the proposed automatic body mass index (BMI) machine.

3. Components of the Proposed Automatic BMI Machine

3.1. The MHT1 Load-Cell Wheatstone Bridge Circuit Implementation

To achieve a high-precision weight measurement with the MHT1 load-cell, it is necessary that an additional circuitry be incorporated which is dedicated to the fine adjustment of the output signal at different loads and also make the necessary individual thermal compensations during the operation of the proposed automatic BMI machine. The typical 3-D views of the MHT1 load-cell is shown in Figure 2 while the technical specifications of the MHT1 load-cell are listed in Table 3 [27].

Table 3. MHT1 load-cell technical specifications.

S/N	Specifications	Units	Range
1.	Capacity	kg	1, 2, 5, 10, 20, 50, 100, 200
2.	Capacity	lb	2, 5, 10, 20, 50, 100, 200, 500
3.	Output	mV/V	1+20% for 1 kg – 20 kg and 2 lb – 50 lb 1.5+20% for 50 kg – 200 kg and 100 lb – 500 lb
4.	Excitation voltage (V dc or V ac)	V	5 (recommended), 10 (max)
5.	Input impedance	Ù	350 nominal (1,000 nominal for 1 kg and 2 kg models)
6.	Output impedance	Ù	350 nominal (1,000 nominal for 1 kg and 2 kg models)
7.	Allowable maximum load	%FS	150
8.	Non-linearity	% FSmax	+0.5
9.	Repeatability	% FSmax	+0.1
10.	Total error	% FSmax	+0.8
11.	Zero balance	% FSmax	2
12.	Zero temperature coefficient	%FS/°C	0.01
13.	Span temperature coefficient	%FS/°C	0.02
14.	Compensated temperature range	°C	–15 to +70
15.	Operating temperature range	°C	–20 to +80
16.	Material	-	Aluminium body (1 – 20 kg) and stainless-steel cover
17.	IP rating	-	IP64

The proposed high-precision MHT1 load-cell Wheatstone bridge circuit is shown in Figure 3. It can be observed that the circuit shown in Figure 3 is different from the basic or conventional Wheatstone bridge circuit with additional circuitry to enhance high precision weight measurement [28–31]. The functions of each additional circuitry are briefly highlighted in the following according to their numbering in Figure 3.

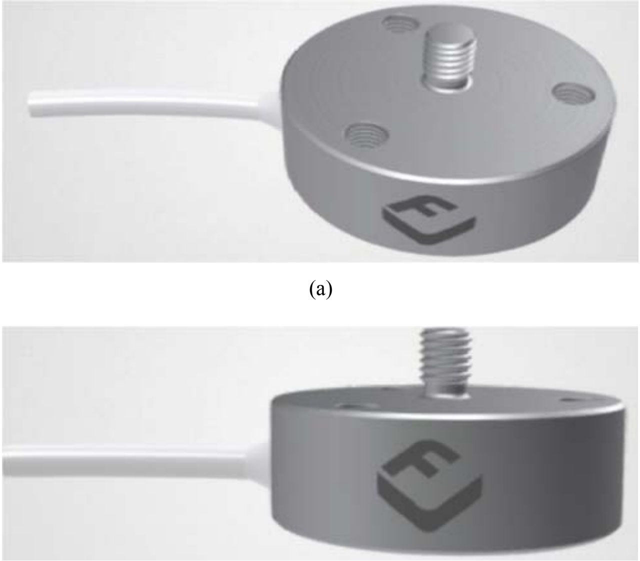
1). R_{AI}: The R_{AI} is the input impedance adjustment resistor. It is used to get an input impedance load-cell value within the specification range as stated in Table 4.

2). R_{AF1}, R_{AG1} and R_{AF2}, R_{AG2}: The R_{AF1}, R_{AG1}, R_{AF2} and R_{AG2} are sensitivity adjustment resistors. R_{AG} resistors are used to perform the coarse adjustment and R_{AF} resistors are used for the fine adjustment of the nominal sensitivity value (Sn) of each load-cell in mV/V.

3). R_{S1}, R_{N1} and R_{S2}, R_{N2}: The R_{S1}, R_{N1}, R_{S2} and R_{N2} are sensitivity compensation resistors with temperature. Resistors R_{N1} and R_{N2} change their nominal resistance values with temperature. R_{S1} and R_{S2} are used to compensate the changes produced in the mechanical elasticity of the load-cells body to obtain a total gain that is stable with temperature.

4). R_{ZT1} and R_{ZT2}: The R_{ZT1} and R_{ZT2} are zero shift temperature compensation resistors. We perform fine adjustments with small thermal compensation resistors to get a stable zero signals with temperature.

5). R_{Z1} and R_{Z2}: The R_{Z1} and R_{Z2} are zero balance resistors. We perform a fine adjustment of the output signal without load (zero of the load-cell) to get a value of 0 mV.



(a)

(b)

Figure 2. The MHT1 load-cell: (a) top view showing pitch circle diameter (PCD), 7 mm deep 3× M3 threaded thru-holes (M3), spring strain relief (SSR), and (b) The side view.

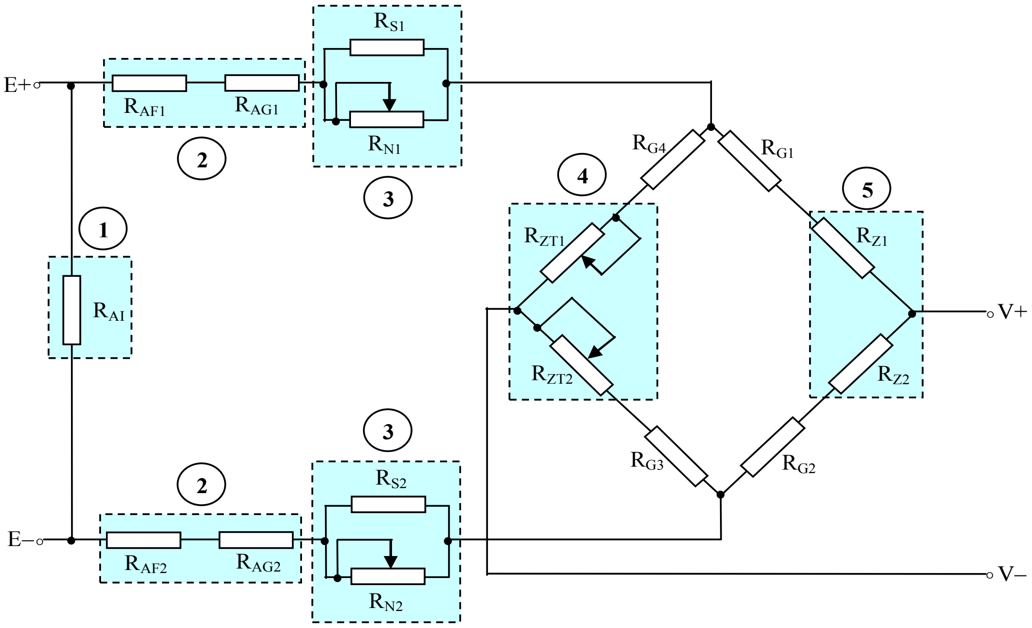


Figure 3. The proposed high-precision MHT1 load-cell Wheatstone bridge circuit.

The output signal V (V+ and V–) of a load-cell at nominal capacity (Ln) is described by the nominal sensitivity (Sn) and the power supply voltage E (E+ and E–). Nominal sensitivity (Sn, in mV/V) is the increase of the output signal (V in mV) when it is applied an increase in force equal to the nominal capacity (Ln in kg), in relation to the supply voltage (E in V).

As an example, we describe the MHT load-cell of 200 kg nominal capacity (Ln) and nominal sensitivity (Sn) of 2 mV/V. This means that the output signal will increase in 2 mV, for each supplied E, when it is applied an increase of load equal to 200 kg. Also, this increase is linear and proportional to the applied load. In the case of a supply voltage of 10 V, then we obtained from 0 to 200 kg of load and output from 0 mV to 40 mV of output signal.

3.2. The HX711 Load-Cell Amplifier

In this work, rather than designing a differential or an instrumentation amplifier as discussed in [28–31] to amplify the output of the MHT1 load-cell Wheatstone bridge circuit, the readily available HX711 load-cell amplifier module, shown in Figure 5, has been adopted. Furthermore, the HX711 load-cell amplifier module can readily be interfaced with the Arduino Mega 2560 embedded system development board used in this work. The simple scheme for interfacing the MHT1 load-cell Wheatstone bridge circuit to the Arduino Mega 2560 board via HX711 load-cell amplifier module is illustrated in Figure 6 as proposed for use in this work.

The HX711 is a precision 24-bit analog-to-digital converter (ADC) designed specifically for weigh scales and industrial control applications to interface directly with bridge sensors [32]. The input multiplexer selects either Channel A or B differential input to low-noise programmable gain amplifier (PGA). Channel A can be programmed with a gain of 64 or 128, corresponding to a full-scale differential input voltage of +20 mV or +40 mV respectively, when a 5 V supply is connected to AVDD analog power supply pin. Channel B has a fixed gain of 32. On-chip power supply regulator eliminated the need for an external supply regulator to provide analog power for the ADC and the sensor. Clock input is flexible. It can be from an external clock source, as crystal, or the on-chip oscillator that does not require any external component. On-chip power reset circuitry simplifies digital interface initialization. There is no programming needed for the internal registers. All controls to the HX711 module are through the input and output pins.

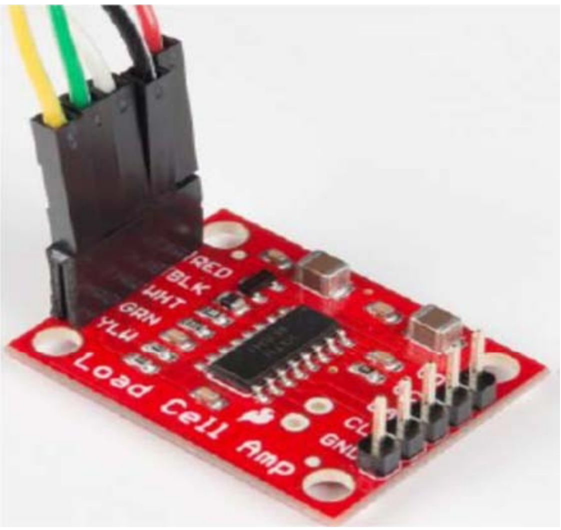


Figure 4. The HX711 load-cell amplifier module.

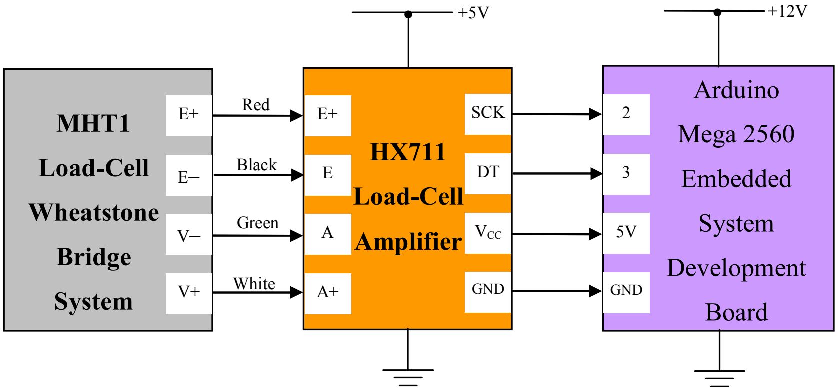


Figure 5. Interfacing scheme of the MHT1 load-cell Wheatstone bridge system to the Arduino Mega 2560 board via HX711 load-cell amplifier module.

The HX711 Implementation

To calibrate the HX711 amplifier module, the complete program for this work shown in Appendix A is uploaded to the Arduino Mega 2560 board, we opened the serial monitor and adjusted the scale factor with 10 kg weight until the correct weight reading was achieved with load-cell weighing system. It is important to note the calibration program for this work was configured to increase the calibration factor by 10, 100, 1000, 10000 by pressing *a, b, c, d* respectively on the keyboard. On the other hand, the calibration factor was decreased by 10, 100, 1000, 10000 by pressing *w, x, y, z* respectively on the keyboard. When the correct weight of 10 kg was achieved, we pressed the "*Enter*" key to send the data to the Arduino Mega 2560 development board.

It was observed that the load-cell results were fluctuating when weights were added and removed during testing. This problem was resolved by developing a separate 5-V power supply unit for the HX711 amplifier module as shown in Figure 4 and Figure 5. Finally, Arduino software does not come with the HX711, which demands that the HX711 library and driver and must be downloaded and installed the HX711 module can function properly.

Figure 6. The HC-SR04 ultrasonic sensor.

3.3. The HC-SR04 Ultrasonic Sensor

In the proposed automatic BMI machine design, the HC-SR04 ultrasonic sensor shown in Figure 6 has been adopted [33,34]. This sensor offers very high accuracy for range detection. Also the stability of the readings is found to be high. They are capable of finding hard as well as soft materials. The HC-SR04 module is a four pin sensor as shown in Figure 8. Two pins ensure the power supply whereas one pins is for transmission and one for echo reception to calculate the height in between the obstacles [33,34]. It works on a 5 V voltage supply and can measure up to 4 meters height.

3.4. Internet-Ready Arduino Mega 2560 Embedded System Development Board

The Internet-ready Arduino Mega 2560 embedded system development board shown in Figure 9 is a microcontroller board based on the ATmega2560 [34–36]. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Mega is compatible with most shields designed for the Arduino Duemilanove or Decimals. The ATmega2560 on the Mega 2560 comes preprogrammed with a bootloader that allows you to upload new code to it without the use of an external hardware Programmer. It communicates using the original STK500 protocol [34–36].

Figure 7. The physical picture and pin definition of the YJD1602A-1 16-by-2 LCD display module.

3.5. The YJD1602A-1 16-by-2 LCD Module

Liquid Crystal Display (LCD) screen is an electronic display module and find a wide range of applications [34,36,37]. The 16x2 LCD display is a very basic module and is very commonly used in various devices and circuits [34,36,37]. These modules are preferred over seven segments and other multi segment LEDs. The reasons being that LCDs are economical; easily programmable; have no limitation of displaying special and even custom character (unlike in seven segments), animations and so on. A 16x2 LCD means it can display 16 characters per line and there are 2 such lines. The YJD1602-A LCD module used in this work is shown in Figure 7.

3.6. Design of an Automatic Power Supply Module

It has been discussed in Section 3.2 using the block diagram of Figure 5 that for the proper operation of the proposed low-cost automatic BMI machine, the Arduino Mega 2560 development board and other components require 12-V while the HX711 load-cell amplifier module requires 5-V to avoid oscillation during loading.

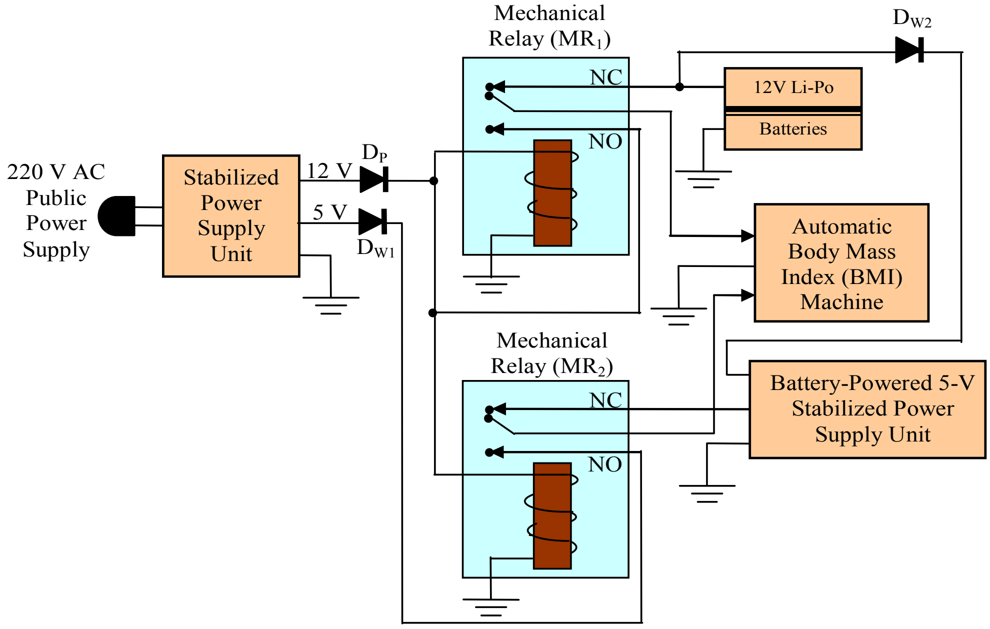


Figure 8. Block diagram of the proposed automatic two-way backup power supply module.

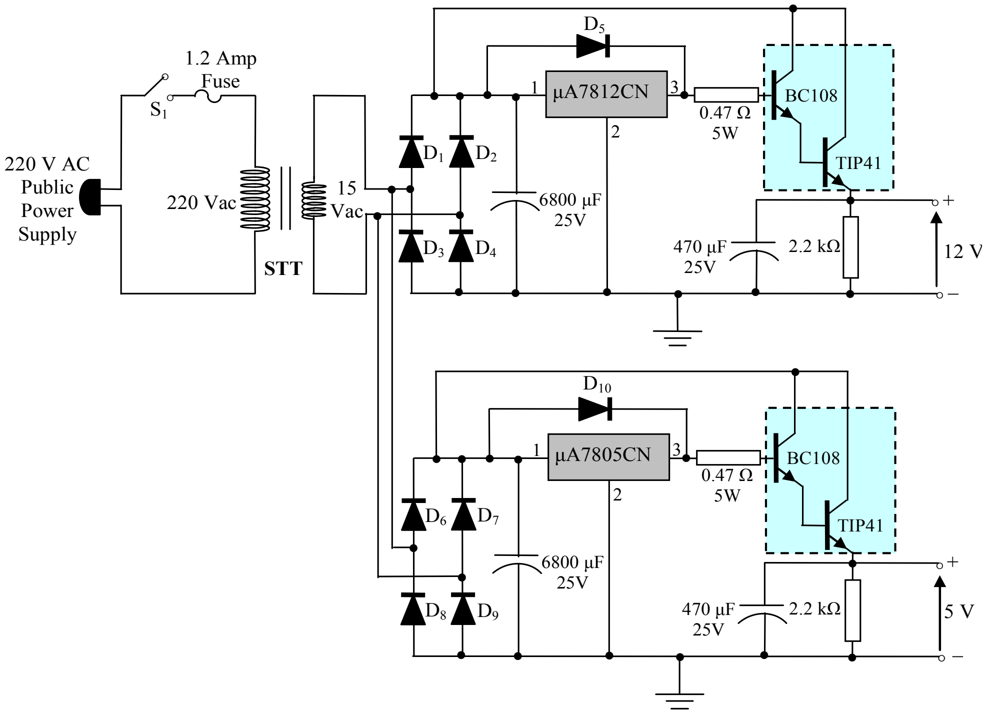


Figure 9. The flowchart for the operation of the automatic BMI machine.

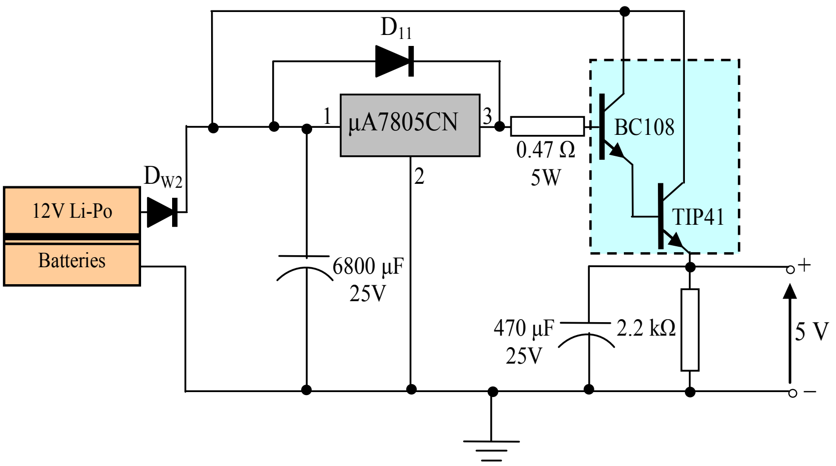


Figure 10. The circuit diagram of the proposed stabilized power supply unit.

The block diagram for the proposed automatic two-way backup power supply module supported with a 12-V Li-Po rechargeable batteries as well as the battery-powered 5-V stabilized power supply unit is shown in Figure 8 while the circuit diagrams of the stabilized power supply unit (SPSU) and battery-powered 5-V SPSU in Figure 8 are shown in Figure 9 and Figure 10 respectively [38]. As it can be seen in Figure 8, the automation of the power supply module is controlled by two mechanical relays MR$_1$ and MR$_2$.

In the presence of public power supply, the SPSU of Figure 8 is activated and it delivers 12-V through diode D$_P$ to MR$_1$ and 5-V through diode D$_{W1}$ to MR$_2$ respectively to the automatic BMI machine for proper operation. Note that the 12-V from D$_P$: *1)* energizes MR$_1$ from normally-closed (NC) terminal to the normally-open (NO) terminal; and *2)* supplies stabilized 12-V that drives that BMI machine for proper operation.

On the other hand, in the absence of public power supply, the output terminal of MR$_1$ and MR$_2$automatically returns to the NC terminals; and the Li-Po battery supplies 12-V directly to the BMI machine and to the battery-powered 5-V stabilized power supply unit for the proper operation of the BMI machine. In this way, the BMI machine can be used both for in-door and out-door BMI measurements and monitoring.

4. Operation, Design and Implementation

4.1. Principle of Operation (Flow Chart)

The principle of operation of the proposed low-cost automatic BMI machine is illustrated in the flow chart shown in Figure 11. As shown in Figure 11, once the BMI machine is powered (START), the machine initializes the MHT1 load-cell system to 0 kg; the HC-SR04 ultrasonic sensor system to 2.135 m and the BMI is initialized to 0 kg/m^2. Whenever the weight is > 0 kg and the height is < 2.135 m; the measurements are captured, verified and the BMI is computed, displayed on an LCD and the buzzer is beeps momentarily. Note that the LCD displays the measured weight, height and BMI. As long as the individual is still on the automatic BMI machine, the measured weight, height and BMI are displayed on the LCD.

The BMI machine automatically adds a wait cycle of one minute immediately the weight, height and BMI are displayed on the LCD. At the expiration of the wait cycle of one minute, the LCD resets the weight to 0 kg, height to 2.135 m and BMI to 0 kg/m^2. Again, the buzzer is beeps momentarily to end (STOP) the BMI determination cycle. The individual must step out of the BMI machine to reset the weight (MHT load-cell sensor) and height (HC-SR04 ultrasonic proximity sensor) measurement systems before a new BMI measurement can be taken.

4.2. Design Methodology

The design and development of the proposed low-cost automatic BMI machine consist of a MHT1 load-cell system arranged in a Wheatstone bridge configuration to measure the weight of the subject ranging from 1 to 200 kg. The electrical resistance of the Wheatstone bridges changes on the direct application of a force on the load-cell and thus generates electrical output in millivolts (mV). The small output signal is amplifier with the use of HX711 load-cell amplifier module. The subject's weight is calculated using Equation (2), where W is the weight of the subject in kg, V (V+ and V–) is the measured output voltage in mV by the application of the weight on the load-cell and the offset voltage, V_o is in millivolts (mV) as well. The offset voltage (V_o) was found to be ≈ 525.05mV.

$$W = gain * \left(\mathbf{V} - V_o\right) \quad (2)$$

where *gain* is the appropriate calibration factor as discussed in Section 3.2.

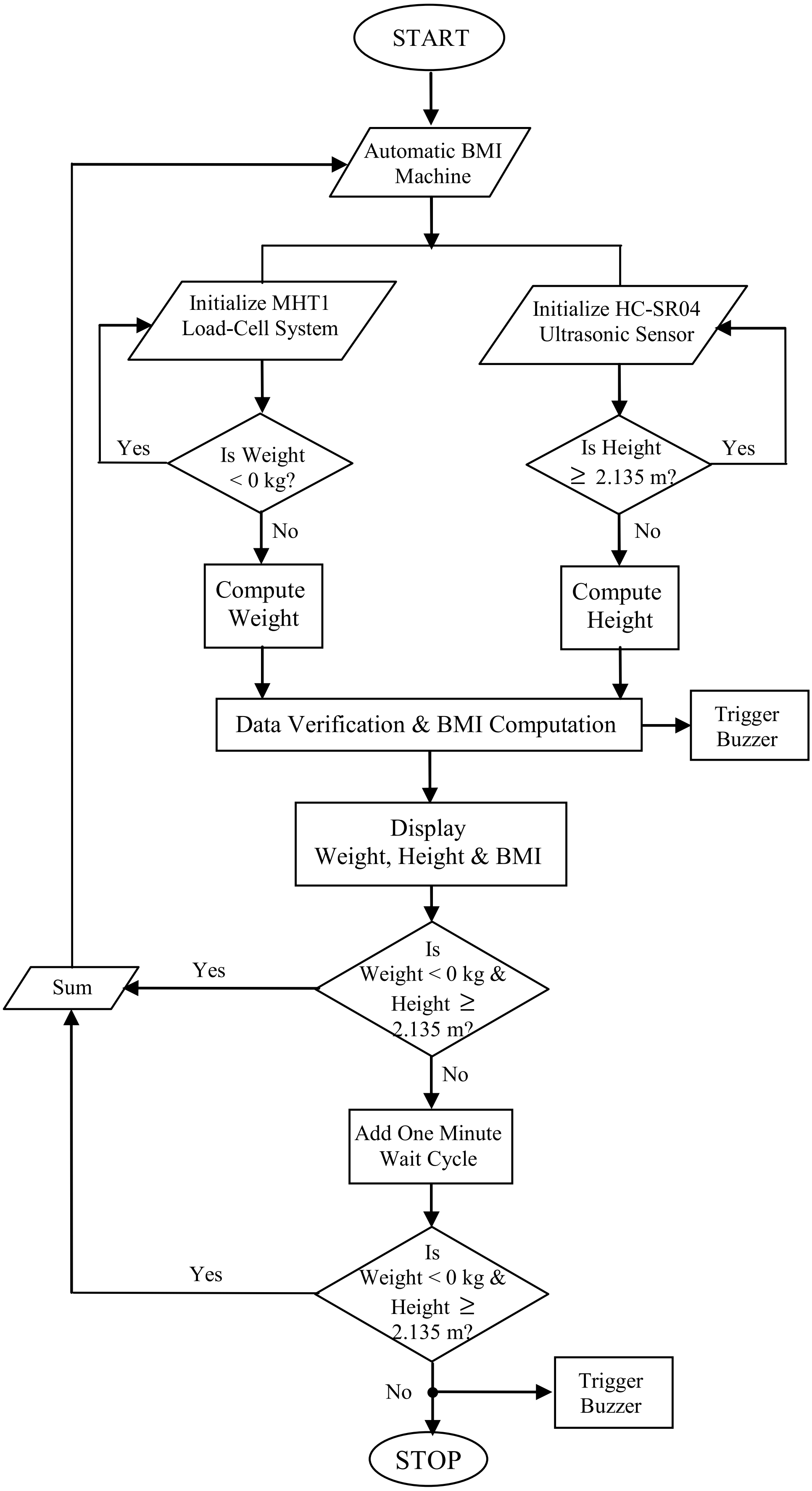


Figure 11. The flowchart for the operation of the automatic BMI machine.

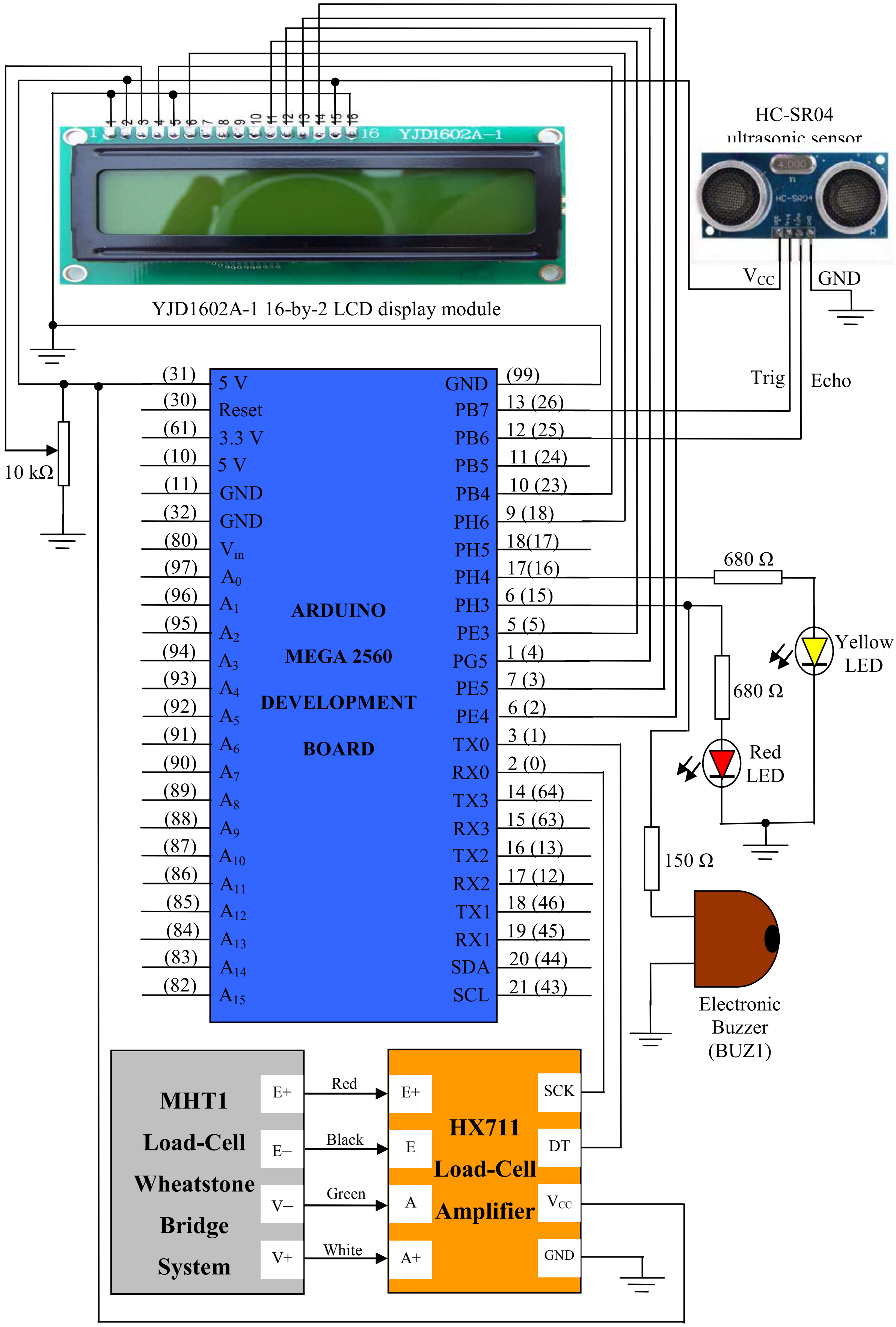


Figure 12. The complete circuit diagram of the proposed automatic BMI machine.

For height measurement of the subject, the HC-SR04 ultrasonic sensor system discussed in Section 3.3 is employed. The maximum height of the proposed BMI machine is arbitrarily set to 2.135 meters high. The calibration of the HC-SR04 sensor is straightforward via programme as listed in the program of Table 7 in the Appendix. The time (t) it takes for the echo pulse reflected by the subject to travel to and fro the HC-SR04 sensor is used by the microcontroller to compute the distance as:

$$d = t * 0.0174 \tag{3}$$

where d is distance in meters and t is time in seconds.

The ultrasonic sensor is at 2.135 metershigh above the MHT1 load-cell weighing system, and then the height (h in meters) is calculated using:

$$h = 2.135 - d_{ss} \tag{4}$$

where d_{SS} represent the distance between the head of the subject and the HC-SR04 ultrasonic sensor. Finally, the BMI computed according to Equation (1) via the Arduino Mega 2560 embedded system development board through the listed program of Table 7 given in the Appendix.

4.3. Hardware–Software Implementation

The complete block diagram schematic showing all the system components and circuits for the proposed low-cost automatic BMI machine is shown in Figure 12. As discussed in Section 2.3, the key components of the machine which include MHT1 load-cell, HX711 load-cell amplifier module, HC-SR04 ultrasonic sensor module, the buzzer with associated signal conditioning circuit, Li-Po backup battery and terminals for the automatic backup power supply system connections as well as the connection ports of all the peripheral and components to the Internet-ready Arduino Mega 2560 embedded system development board.

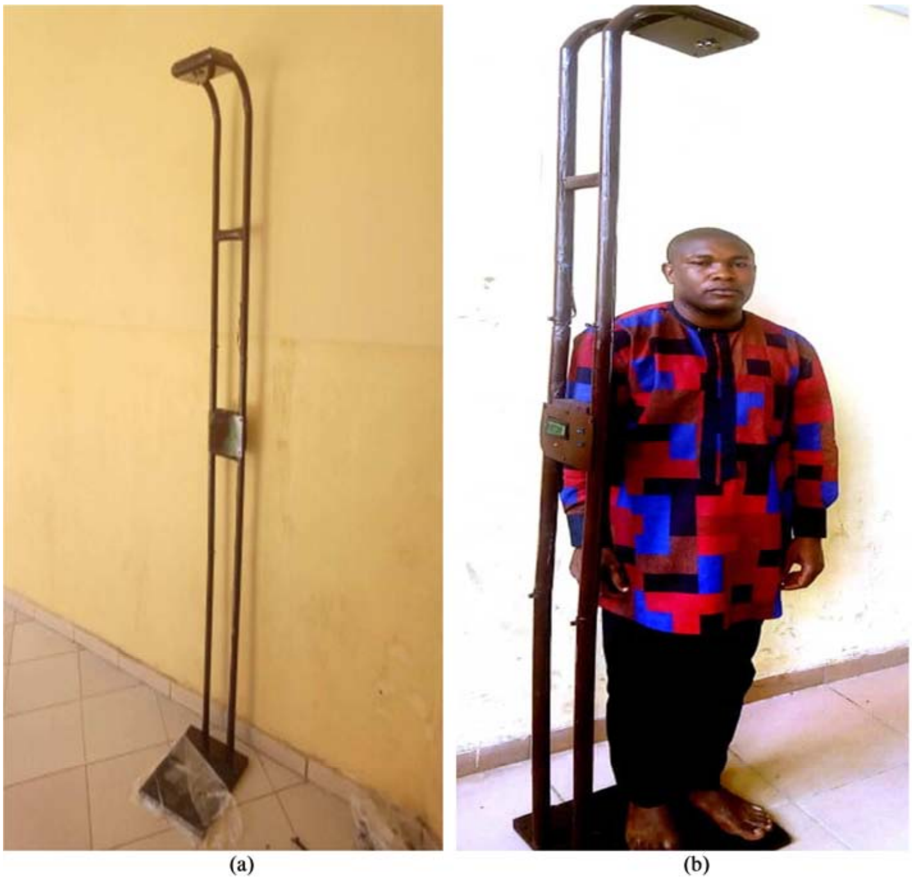

(a) (b)

Figure 13. The proposed automatic BMI machine: (a) shows the isometric view and (b) BMI measurement with the BMI machine.

The complete BMI machine operation is controlled by the software program loaded into the internal memory of Arduino Mega 2560 embedded system development board. The program is written in Arduino programming language C++. Arduino IDE 1.6.4 is used to compile and upload the program. Board menu in Arduino IDE and upload the sketch. In this project, external header files are not required for programming. The Arduino board is connected to the development computer and the correct COM port in Arduino IDE is selected. The program/sketch is used to compile the complete program code to the target board. The complete program for the implementation of the automatic BMI machine is given in Table 7 of the Appendix.

5. Results and Discussions

The designed, developed and assembled low-cost automated BMI machine is shown in Figure 13(a) while the operational demonstration of the machine for a sample BMI measurement of an individual (subject) is shown in Figure 13(b).

In order to investigate the performance and measurement accuracy, measurements were performed on 60 randomly selected students of age between 15 and 36 years at AFE Babalola University, Ado-Ekiti, Ekiti State – Nigeria.

The measurements obtained automatically from the machine were compared with those obtained manually using commercially floor-type *HANA* manual weighing machine (i.e. analog weighing machine) as well as the manual height measurements using 25 meter length tape on the 60 subjects. The correlation between the measurements obtained with automatic BMI machine and manual method for height, weight and BMI are shown in Figure 14 while their corresponding errors are shown in Figure 15. The close matching of these measurements are evident in Figure 14 with small mean errors of 0.0133, 1.8125, and 1.0733 for height, weight and BMI respectively.

The 60 subjects consist of 22 male and 38 female subjects. The measurements using the constructed automatic BMI machine and the measurements obtained manually for the 22 male and 38 female subjects are tabulated in Table 4 and Table 5 respectively. According to WHO, healthy subject can be classified according to Table 1 with the risk of co-morbidity [7]. In this study, the classification of the 60 randomly chosen subjects based on their automatic BMI measurements and their risk of co-morbidity are shown in Table 6.

According to Table 1 and the results shown in Table 6, it can be observed that 3 students are underweight with low risk of co-morbidity, 26 are normal with average risk of co-morbidity, 16 students are overweight with increased risk of co-morbidity, 10 in Class 1 obesity with moderate risk of co-morbidity, 4 in Class II obesity with severe risk of co-morbidity while only 1 is in Class III obesity with very severe risk of co-morbidity.

A careful study of Table 6 reveals that a 36 years old male subject on serial number 10 has a BMI of 18.3988 kg/m^{2}with a height of 1.71 meters and a weight of 53.8 kg. Another 17 years old female subject on serial number 43 has a BMI of 18.4951 kg/m^2 with a height of 1.78 meters and a weight of 58.6 kg as well as the second 16 years old female subject on serial number 44 has a BMI of 18.4813 kg/m^2 with a height of 1.77 meters and a weight of 57.9 kg. According to Table 1 [7], these three subjects are underweight with low risk of co-morbidity. The big question that comes to mind is why, how and what could be responsible for a teenager be underweight?

Table 4. Automated and manually measured of height, weight and BMI for 22 Male Students of ABUAD.

S/N	**Age(in Years)**	**Data measured using the constructed Automatic BMI machine**			**Manually measured Data**		
		Height(m)	**Weight(kg)**	**BMI(kg/m^2)**	**Height(m)**	**Weight(kg)**	**BMI(kg/m^2)**
1	19	1.66	73.1	26.5278	1.68	69.7	24.6953
2	19	1.56	53.7	22.0661	1.56	49.5	20.3402
3	18	1.67	60.2	21.5856	1.69	56.2	19.67772
4	18	1.64	79.7	29.6327	1.65	77.5	28.4665
5	17	1.62	100.8	38.4088	1.64	103	38.2957
6	17	1.63	86.5	32.5567	1.66	83	30.1205
7	18	1.68	83.6	29.6202	1.68	79.5	28.1675
8	19	1.58	96.3	38.5755	1.59	95	37.5776
9	21	1.79	69.3	21.6285	1.8	70.5	21.7593
10	35	1.71	53.8	18.3988	1.71	50.5	17.2703
11	32	1.61	90.9	35.0681	1.62	89.5	34.1030
12	33	1.65	96.9	35.5923	1.65	95	34.8944
13	16	1.64	74.3	27.6249	1.65	70.45	25.8770
14	17	1.65	63.6	23.3609	1.66	59	21.4109
15	19	1.57	61.7	25.0314	1.58	67	26.8386
16	36	1.83	103	30.7564	1.85	103	30.0950
17	21	1.75	75.9	24.7837	1.75	75	24.4898
18	20	1.74	81.4	26.8860	1.74	79.9	26.3905
19	18	1.67	64.5	23.1274	1.67	61.5	22.0517
20	17	1.67	87.6	31.4102	1.69	85	29.7609
21	34	1.64	73.4	27.2903	1.65	70.1	25.7484
22	21	1.79	137.1	42.7889	1.79	140.5	43.8501

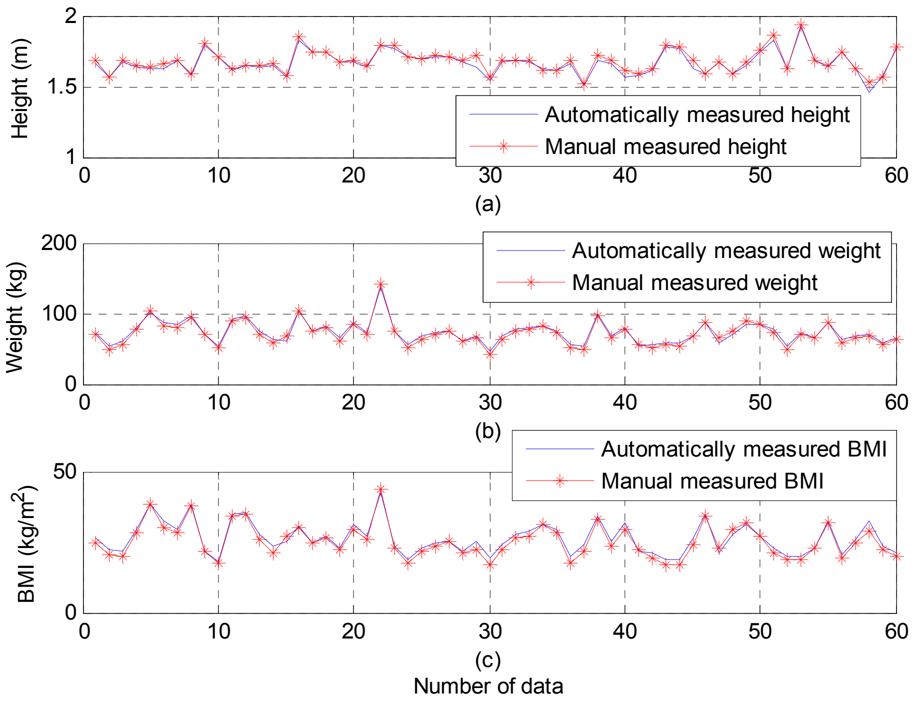


Figure 14. Comparison of automatic BMI machine and manual measurements: (a) height, (b) weight, and (c) BMI.

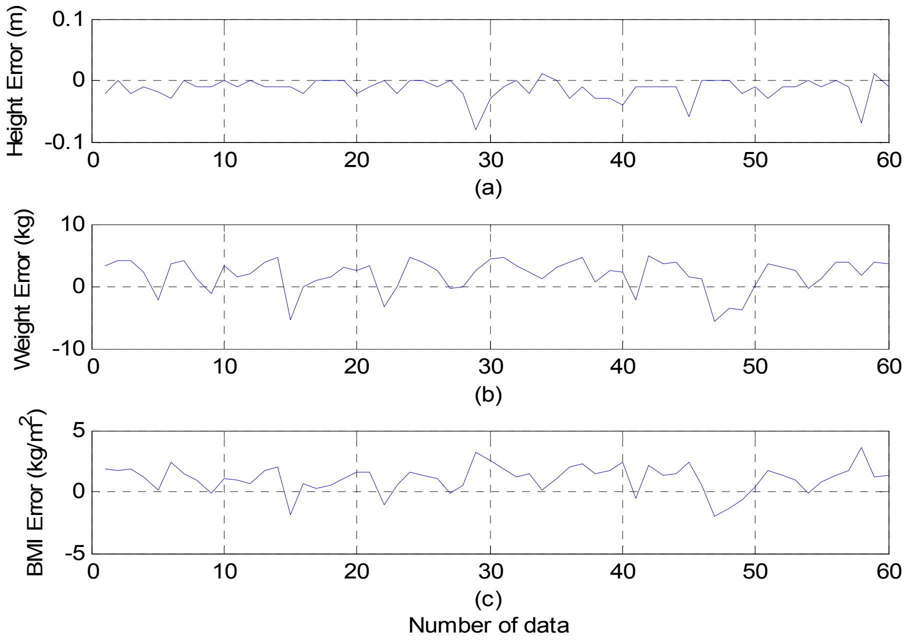


Figure 15. Measurement errors between automatic BMI machine and manual measurements: (a) height, (b) weight, and (c) BMI.

The shortest subject among the 60 students is a female with serial number 58 has a height of 1.46 meters with weight 69.6 kg and BMI of 32.6515 kg/m^2 which accidentally fall in moderate risk of co-morbidity category with class I obesity. The advice here is that the subject should engage in sporting activities and/or consult a dietician to reduce her weight for fitness.

Among the 60 subjects, a male student with serial number 22 has the highest weight of 137.1 kg with a height of 1.79 meters and BMI of 42.7889 which accidentally fall in very severe risk of co-morbidity with Class III obesity. This student is strictly advised to see a medical doctor for urgent attention as well consult a dietician. Furthermore, regular exercise is also recommended.

Furthermore, among the 60 subjects, a female student with serial number 30 has the smallest weight of 45.8 kg with a height of 1.54 meters and BMI of 19.3119 which luckily falls in the moderate risk of co-morbidity category with normal weight. The tallest subject among the 60 students is a female with serial number 53 has a height of 1.92 meters with weight 73.1 kg and BMI of 19.8296 which luckily falls in the moderate risk of co-morbidity category with normal weight. This subject is health and should keep fit with exercises and monitor her diets.

Table 5. Automated and Manually Measured height, weight and BMI for 38 Female Students of ABUAD.

S/N	Age(in Years)	Data measured using the constructed Automatic BMI machine			Manually measured Data		
		Height(m)	Weight(kg)	BMI(kg/m^2)	Height(m)	Weight(kg)	BMI(kg/m^2)
1	18	1.77	73.9	23.5884	1.79	74	23.0954
2	18	1.71	55.6	19.0144	1.71	51	17.4413
3	17	1.70	66.7	23.0796	1.70	63	21.7993
4	24	1.71	72.4	24.7598	1.72	69.9	23.6276
5	21	1.71	74.0	25.3069	1.71	74.3	25.4095
6	18	1.67	60.5	21.6931	1.69	60.6	21.2177
7	19	1.64	68.6	25.5057	1.72	66	22.3094
8	18	1.54	45.8	19.3119	1.57	41.5	16.8364
9	19	1.67	67.5	24.2031	1.68	63	22.3214
10	18	1.69	78.4	27.4500	1.69	75.1	26.2946
11	21	1.67	80.3	28.7927	1.69	78	27.3100
12	19	1.62	82.3	31.3595	1.61	81	31.2488
13	17	1.61	75.9	29.2813	1.61	73	28.1625
14	18	1.66	54.9	19.9231	1.69	51	17.8565
15	20	1.51	54.6	23.9463	1.52	50	21.6413
16	20	1.69	97.7	34.2075	1.72	97	32.7880
17	20	1.66	68.9	25.0036	1.69	66.5	23.2835
18	17	1.57	79.2	32.1311	1.61	77	29.7056
19	16	1.58	54.5	21.8314	1.59	56.7	22.4279
20	17	1.61	55.4	21.3726	1.62	50.5	19.2425
21	17	1.78	58.6	18.4951	1.79	55	17.1655
22	16	1.77	57.9	18.4813	1.78	54	17.0433
23	15	1.62	68.8	26.2155	1.68	67.3	23.87
24	15	1.59	88	34.8087	1.59	86.8	34.3341
25	16	1.67	58.7	21.0477	1.67	64.3	23.0557
26	19	1.59	70.4	27.8470	1.59	73.9	29.2314
27	20	1.65	85.6	31.4417	1.67	89.5	32.0915
28	21	1.75	83.6	27.2980	1.76	83.5	26.9564
29	19	1.83	77.1	23.0225	1.86	73.5	21.2452
30	17	1.62	52.9	20.1570	1.63	49.9	18.7813
31	20	1.92	73.1	19.8296	1.93	70.5	18.9267
32	18	1.68	65.2	23.1009	1.68	65.5	23.2072
33	18	1.64	87.1	32.3840	1.65	86	31.5886
34	20	1.75	62.9	20.5388	1.75	59	19.2653
35	17	1.62	68.7	26.1774	1.63	65	24.4646
36	19	1.46	69.6	32.6515	1.53	68	29.0487
37	20	1.58	59.2	23.7141	1.57	55.5	22.5161
38	19	1.77	66.1	21.0987	1.78	62.5	19.7260

Table 6. Verification of automatically BMI against the risk of co-morbidity for 60 randomly chosen subjects.

S/N	Years	Sex	Height	Weight	BMI	Risk of Co-Morbidity
1	19	Male	1.66	73.1	26.5278	Overweight and increased risk of co-morbidities
2	19	Male	1.56	53.7	22.0661	Normal weight and average risk of co-morbidities
3	18	Male	1.67	60.2	21.5856	Overweight and increased risk of co-morbidities
4	18	Male	1.64	79.7	29.6327	Overweight and increased risk of co-morbidities
5	17	Male	1.62	100.8	38.4088	Obese class II and severe risk of co-morbidities
6	17	Male	1.63	86.5	32.5567	Obese class I and moderate risk of co-morbidities
7	18	Male	1.68	83.6	29.6202	Overweight and increased risk of co-morbidities
8	19	Male	1.58	96.3	38.5755	Obese class II and severe risk of co-morbidities
9	21	Male	1.79	69.3	21.6285	Normal weight and average risk of co-morbidities
10	35	Male	1.71	53.8	18.3988	Underweight and low risk of co-morbidities
11	32	Male	1.61	90.9	35.0681	Obese class I and moderate risk of co-morbidities
12	33	Male	1.65	96.9	35.5923	Obese class II and severe risk of co-morbidities
13	16	Male	1.64	74.3	27.6249	Overweight and increased risk of co-morbidities
14	17	Male	1.65	63.6	23.3609	Normal weight and average risk of co-morbidities
15	19	Male	1.57	61.7	25.0314	Overweight and increased risk of co-morbidities
16	36	Male	1.83	103	30.7564	Obese class I and moderate risk of co-morbidities
17	21	Male	1.75	75.9	24.7837	Normal weight and average risk of co-morbidities
18	20	Male	1.74	81.4	26.8860	Overweight and increased risk of co-morbidities

S/N	Years	Sex	Height	Weight	BMI	Risk of Co-Morbidity
19	18	Male	1.67	64.5	23.1274	Normal weight and average risk of co-morbidities
20	17	Male	1.67	87.6	31.4102	Obese class I and moderate risk of co-morbidities
21	34	Male	1.64	73.4	27.2903	Overweight and increased risk of co-morbidities
22	21	Male	1.79	137.1	42.7889	Obese class III and very severe risk of co-morbidities
23	18	Female	1.77	73.9	23.5884	Normal weight and average risk of co-morbidities
24	18	Female	1.71	55.6	19.0144	Normal weight and average risk of co-morbidities
25	17	Female	1.70	66.7	23.0796	Normal weight and average risk of co-morbidities
26	24	Female	1.71	72.4	24.7598	Normal weight and average risk of co-morbidities
27	21	Female	1.71	74.0	25.3069	Overweight and increased risk of co-morbidities
28	18	Female	1.67	60.5	21.6931	Normal weight and average risk of co-morbidities
29	19	Female	1.64	68.6	25.5057	Overweight and increased risk of co-morbidities
30	18	Female	1.54	45.8	19.3119	Normal weight and average risk of co-morbidities
31	19	Female	1.67	67.5	24.2031	Normal weight and average risk of co-morbidities
32	18	Female	1.69	78.4	27.4500	Overweight and increased risk of co-morbidities
33	21	Female	1.67	80.3	28.7927	Overweight and increased risk of co-morbidities
34	19	Female	1.62	82.3	31.3595	Obese class I and moderate risk of co-morbidities
35	17	Female	1.61	75.9	29.2813	Overweight and increased risk of co-morbidities
36	18	Female	1.66	54.9	19.9231	Normal weight and average risk of co-morbidities
37	20	Female	1.51	54.6	23.9463	Normal weight and average risk of co-morbidities
38	20	Female	1.69	97.7	34.2075	Obese class I and moderate risk of co-morbidities
39	20	Female	1.66	68.9	25.0036	Normal weight and average risk of co-morbidities
40	17	Female	1.57	79.2	32.1311	Obese class I and moderate risk of co-morbidities
41	16	Female	1.58	54.5	21.8314	Normal weight and average risk of co-morbidities
42	17	Female	1.61	55.4	21.3726	Normal weight and average risk of co-morbidities
43	17	Female	1.78	58.6	18.4951	Underweight and low risk of co-morbidities
44	16	Female	1.77	57.9	18.4813	Underweight and low risk of co-morbidities
45	15	Female	1.62	68.8	26.2155	Normal weight and average risk of co-morbidities
46	15	Female	1.59	88	34.8087	Obese class II and severe risk of co-morbidities
47	16	Female	1.67	58.7	21.0477	Normal weight and average risk of co-morbidities
48	19	Female	1.59	70.4	27.8470	Overweight and increased risk of co-morbidities
49	20	Female	1.65	85.6	31.4417	Obese class I and moderate risk of co-morbidities
50	21	Female	1.75	83.6	27.2980	Overweight and increased risk of co-morbidities
51	19	Female	1.83	77.1	23.0225	Normal weight and average risk of co-morbidities
52	17	Female	1.62	52.9	20.1570	Normal weight and average risk of co-morbidities
53	20	Female	1.92	73.1	19.8296	Normal weight and average risk of co-morbidities
54	18	Female	1.68	65.2	23.1009	Normal weight and average risk of co-morbidities
55	18	Female	1.64	87.1	32.3840	Obese class I and moderate risk of co-morbidities
56	20	Female	1.75	62.9	20.5388	Normal weight and average risk of co-morbidities
57	17	Female	1.62	68.7	26.1774	Overweight and increased risk of co-morbidities
58	19	Female	1.46	69.6	32.6515	Obese class I and moderate risk of co-morbidities
59	20	Female	1.58	59.2	23.7141	Normal weight and average risk of co-morbidities
60	19	Female	1.77	66.1	21.0987	Normal weight and average risk of co-morbidities

6. Conclusion

Body mass index (BMI) is a measure which represents the body fat percentage against the weight of organs, muscles or bones. A low-cost automatic BMI machine has been successfully designed, constructed, validated and deployed for BMI measurements using 60 randomly selected students of age between 15 and 36 years at AFE Babalola University, Ado-Ekiti – Nigeria. It is evident from the discussion of the results and discussions for the few cases considered, that several questions and deductions can still be made from other subjects with relevant advice where necessary to the subjects in question.

This BMI machine was designed while considering several factors such as economic applications, design economy, availability of components from local markets, research materials on BMI which are relatively scarce, efficiency, compatibility and portability, ruggedity and durability. The performance of the design BMI machine after testing met the design specifications.

The electronic BMI is such a device that could find application in hospitals, clinics, and even pharmacies. It can be placed at Gyms, airports, hotels, bus-stops and other social places as well. It can also be used for commercial purposes by installing a fool proof coin or note currency acceptor system.

As a future direction, the automatic low-cost BMI machine presented in work can be re-designed and constructed in such a way that it should display the state of health of a particular individual along side the BMI. Hence, Additional module such as blood pressure and other parameters can be measured. Integrated of data-logging facilities which are fully supported By the Internet-ready Arduino Mega 2560 real-time embedded system development board would be a novel innovation. Introducing an automatic charger for the Li-Po battery would eliminate external charging and increase the life-span of the battery. Although, the MHT1 load-cell only accommodate weights between 1 to 200 kg which is acceptable for the current machine; however, it is straightforward to increase is weight capacity by simply replacing the MHT1 with a load-cell with higher weight capacity and reprogram and recalibrate the load-cell with the HX711 load-cell amplifier module.

Appendix

Table 7. Software and program code for the implementation of the low-cost automatic BMI machine.

```
#include <LiquidCrystal.h>
//(RS, E, D4, D5, D6, D7)
LiquidCrystallcd(12, 11, 5, 4, 3, 2)
intpingPin = 7;
intinPin = 6;
float time=0, distance=0, BMI=0, dist=0;

#include "HX711.h"
// HX711.DOUT- pin A1
// HX711.PD_SCK - pin A0
HX711 scale(A1, A0);

void setup() {
lcd.begin(16, 4);
pinMode(pingPin, OUTPUT);
pinMode(inPin, INPUT);
pinMode(13, INPUT);
pinMode(10, OUTPUT);
Serial.begin(38400);
Serial.println(scale.read());
// print a raw reading from the ADC

Serial.print("read average:\t\t ");
Serial.println(scale.read_average(20));
// print the average of 20 readings from the ADC

Serial.print("get value: \t\t ");
Serial.println(scale.get_value(5));
// print the average of 5 readings from the ADC minus the //tare weight (not set yet)

Serial.print("get units: \t\t ");
Serial.println(scale.get_units(5), 1);
// print the average of 5 readings from the ADC minus //tare weight (not set) divided by the SCALE parameter //(not set yet)
scale.set_scale(2280.f);
```

```
lcd.print("");
delay(4000);}
void loop(){
if (digitalRead(13)==HIGH)
{
delay(500);
digitalWrite(pingPin, LOW);
delayMicroseconds(2);
digitalWrite(pingPin, HIGH);
delayMicroseconds(10);
digitalWrite(pingPin, LOW);
delayMicroseconds(2);

time = pulseIn(inPin, HIGH);
distance=time*348 /20000;

lcd.clear();
lcd.setCursor(0, 0);
lcd.print("CALCULATING");
lcd.setCursor(0, 1);
lcd.print("DISTANCE");
lcd.setCursor(0, 2);
lcd.print("WEIGHT");
lcd.setCursor(0, 3);
lcd.print("BMI");
delay(400);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("BMI SYSTEM");
lcd.setCursor(0, 1);
lcd.print("distance:");
lcd.print(distance/100);
lcd.print("m");
lcd.setCursor(0, 2);
lcd.print("Weight:");
```

```
// this value is obtained by calibrating the scale with //known weights; see the README for details
scale.tare();// reset the scale to 0
Serial.println("After setting up the scale:");
Serial.print("read: \t\t");
Serial.println(scale.read());
// print a raw reading from the ADC
Serial.print("read average:\t\t ");
Serial.println(scale.read_average(20));
// print the //average of 20 readings from the ADC
Serial.print("get value: \t\t ");
// print the average of 5 readings from the ADC minus //the tare weight, set with tare()
Serial.println(scale.get_value(5));
Serial.print("get units: ");
Serial.println(scale.get_units(5), 1);
// print the average of 5 readings from the ADC minus //tare weight, divided by the SCALE parameter set with //set_scale
lcd.setCursor(0, 0);
lcd.print("BMI SYSTEM");
lcd.setCursor(0, 1);
lcd.print("DESIGNED BY");
lcd.setCursor(0, 2);
lcd.print(" PATRICK OLAJIDE");
lcd.setCursor(0, 3);
```

```
lcd.print(scale.get_units()*0.1, 1);
lcd.print("kg");
dist=distance/100;
BMI=((scale.get_units()*0.1, 1)/((dist)*(dist)));
lcd.setCursor(0, 3);
lcd.print("BMI:");
lcd.print(BMI);
lcd.print("kg/m2");
scale.power_down();

digitalWrite(10, HIGH);
delay(5000);
digitalWrite(10, LOW);
scale.power_up();
} else
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("BMI SYSTEM");
lcd.setCursor(0, 1);
lcd.print("DESIGNED BY");
lcd.setCursor(0, 2);
lcd.print(" PATRICK OLAJIDE");
lcd.setCursor(0, 3);
lcd.print("");
delay(500);
```

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors wish to acknowledge the staff and student of Afe Babalola University, Ado-Ekiti, Nigeria for their time, patience, constructive criticism, and allowing their measurements to be taken and used for the validation of the design and constructed low-cost automatic BMI machine.

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