DEVELOPMENT OF AN AUTOMATIC BODY MASS INDEX MACHINE

Vincent A. AKPAN[1], Joshua B. AGBOGUN[2] and Oluwatosin T. OMOTEHINWA[3]
[1*] Department of Biomedical Technology, The Federal University of Technology, Akure, Nigeria
[2] Department of Mathematical Sciences, Kogi State University, Anyingba, Nigeria
[3] Department of Mathematical Sciences, Achievers University, Owo, Nigeria

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Abstract: *Obesity, which refers to excess body fat in the body, has become a popular and important public health problem. Body mass index (BMI) is metric currently in use for defining obesity or anthropometric height/weight characteristics in adults and for classifying them in groups. It is unarguable that rather than error-prone manual BMI calculations, an automatic BMI computation is a preferred option. This paper presents the design and development of a low-cost automatic BMI machine for indoor and out-door use. The proposed automatic BMI machine consists of 7 main sections, namely: 1). MHT1 load-cell arranged in Wheatstone bridge configuration which incorporates internally mounted SR-120 foil-type strain gauges; 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 proposed automatic BMI machine have been designed, constructed and deployed for automatic BMI measurements, and the results have been compared with manual measurements. The performance of the proposed low-cost automatic BMI machine shows that it can be used in homes, hospitals, companies as well as in any environments where routine BMI monitoring may be desired. 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, Internet-of-Things, Obesity, Risk of Co-Morbidity

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 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:

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

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].

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

*Department of Biomedical Technology, The Federal University of Technology, Akure, Nigeria and Email Address: vaakpan@futa.edu.ng

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

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.

1.1. 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 [11].

Presently, height and weight measurement is one of the major aspects of the recruitment process of Defense and Police [12]. 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 process of Defense and Police. In the proposed method by Honade, webcam is used to capture the image of a person, whose height is to be measured [12]. To capture the image by using webcam image acquisition toolbox is used. After capturing the image of the candidate, the processing is done on the image by using efficient digital image processing tool that comes with MATLAB. Also, 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 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. In this way microcontroller from the AVR family was applied for sampling of analog signal and also monitoring weight. If this technology is paired with a scale, a person's BMI can easily be calculated. 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 GUI (graphical user interface) is made for the user to input a measured height and weight of an individual and press a button that calculates the BMI automatically [13]. These system-based applications, also called BMI calculators, became popular in the early 1990s and was mostly used in specialized hospitals and health offices.

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 [14]. Devices with similar concept, although with higher resolutions, are used in industrial metrology applications, where they are called height gauges.

A strain gauge-type load cell as a model was proposed and designed for measuring weight [15]. Four methods of fixing and balancing Wheatstone bridge were considered and one way was achieved eventually which was given the best Wheatstone bridge's output. For amplifying and measuring of changing resistance and voltage in Wheatstone Bridge, four current ways of amplifying and measuring were applied and with doing some modification in one of them construction of the main model was made. In this way microcontroller from the AVR family was applied for sampling of analog signal and also monitoring weight. Finally, by using Probabilistic Neural Network, fault detection at zero level was carried out, hence, safety of the system was increased [15].

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 [16]. The hardware of the project consists of a weighing mechanism i.e. 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 weight of the person is calculated in kilograms and the height in meters in accordance of the BMI standard formula given in (1). 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 [17]. The hardware of the project consists of a load-cell for body weight measurement while the height measurement was achieved using ultrasonic sensor.

2. BLOCK DIAGRAM AND OVERVIEW OF THE PROPOSED BMI MACHINE

The block diagram of the proposed low-cost automatic BMI machine is shown in Fig. 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 12V 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.

3. DESIGN OF COMPONENTS AND ASSEMBLY

3.1 High-Precision MHT1 Load-Cell Wheatstone Bridge Circuit Implementation

The MHT1 compression button force sensor (1–200kg) is a hazardous environment load cell classified under types of thin

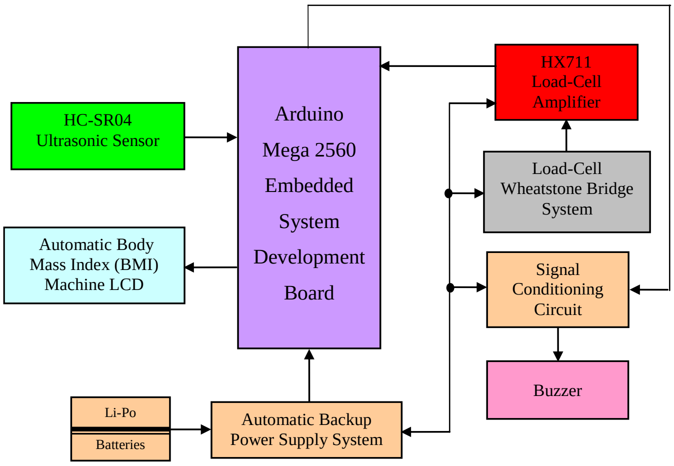

Fig. 1: Block diagram of the proposed automatic body mass index (BMI) machine.

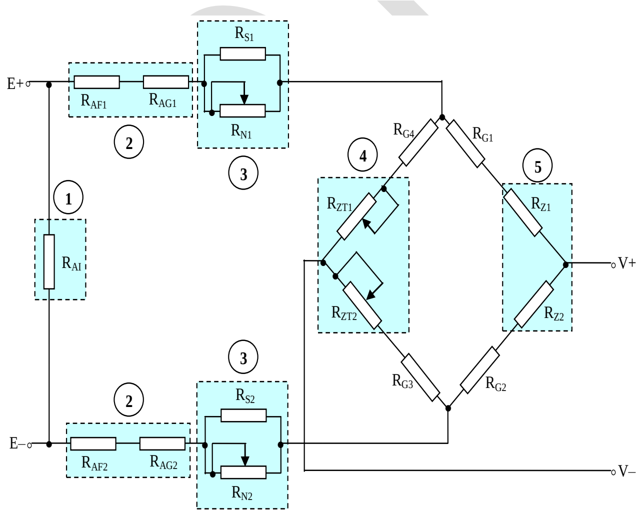

Fig. 2: The proposed high-precision MHT1 load-cell Wheatstone bridge circuit.

load-cells [18–20]. The choice for MHT1 load-cell is its capability to measure weight from 1 kg up to 200 kg which are the weight range typical for this work.

The principle of load-cell operation is similar to normal strained arrangement which is usually in a Wheatstone bridge format [20–24]. The only difference being that in load-cells the strain gauges have already been mounted on a predesigned beam with advanced technologies.

To achieve a high-precision weight measurement with the MHT1 load-cell, it is necessary an additional circuitry to the strain gauges, 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 proposed high-precision MHT1 load-cell Wheatstone bridge circuit is shown in Fig. 2. It can be observed the circuit shown in Fig. 2 is different from the basic or conventional Wheatstone bridge circuit with additional circuitry to enhance high precision weight measurement. The functions of each additional circuitry are briefly highlighted in the following according to their numbering in Fig. 2.

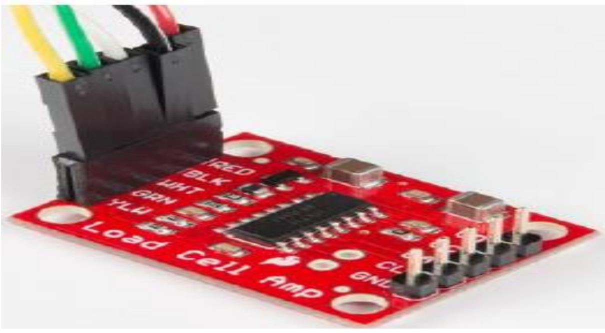

Fig. 3: The HX711 load-cell amplifier module.

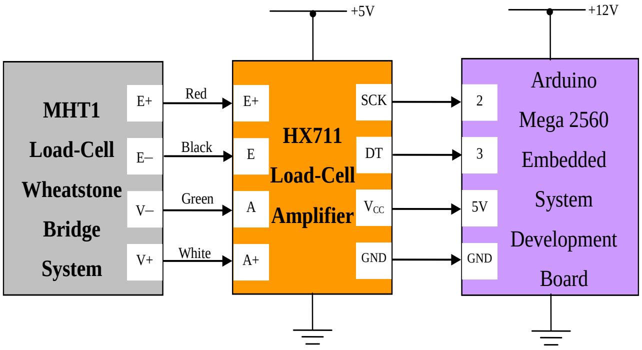

Fig. 4: Interfacing scheme of the MHT1 load-cell Wheatstone bridge system to the Arduino Mega 2560 board via HX711 load-cell amplifier module.

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 [20].

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.

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 2mV/V.

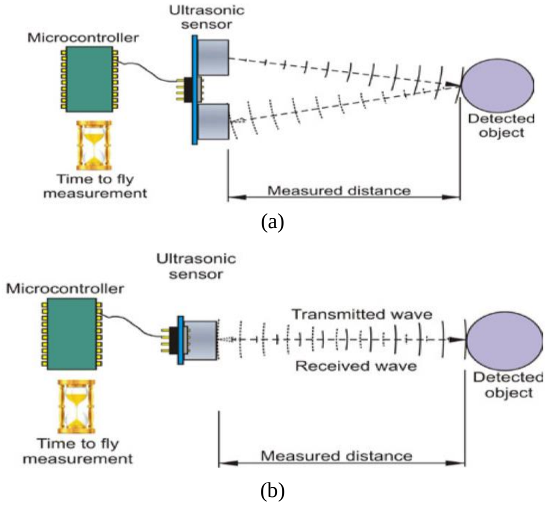

Fig. 5: The basic working principle of the ultrasonic sensor: (a) top view and (b) side view.

Fig. 6: The HC-SR04 ultrasonic sensors.

This means that the output signal will increase in 2mV, for each supplied **E**, when it is applied an increase of load equal to 200kg. Also, this increase is linear and proportional to the applied load. In the case of a supply voltage of 10V, then we obtained from 0 to 200kg of load and output from 0mV to 40mV of output signal.

3.2. The HX711 Load-Cell Amplifier

In this work, rather than designing a differential or an instrumentation amplifier as detailed in [21–24] to amplify the output of the MHT1 load-cell Wheatstone bridge circuit, the readily available HX711 load-cell amplifier module, shown in Fig. 3, 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 [25]. 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 Fig. 4 as proposed for use in this work.

3.2.1. 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. Then, we opened the serial monitor and adjusted the scale factor with 10 kg weight until the correct weight reading is achieved with the 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.

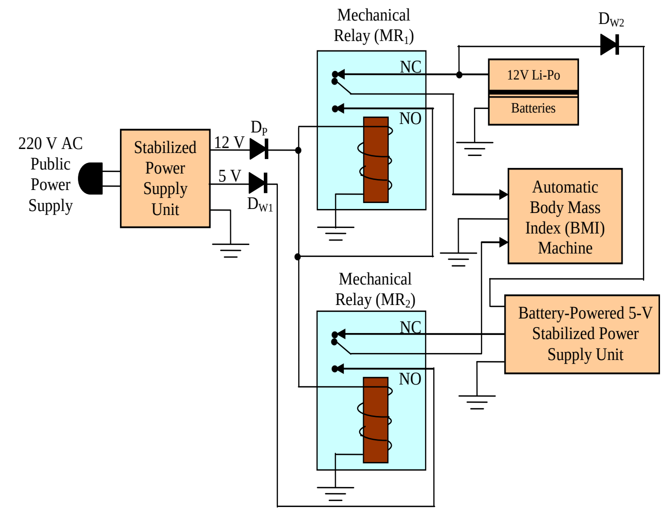

Fig. 7: Block diagram of the proposed automatic two-way backup power supply module.

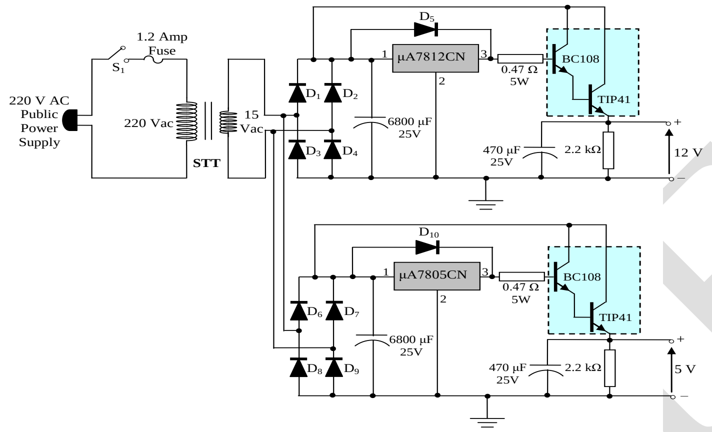

Fig. 8: The flowchart for the operation of the automatic BMI machine.

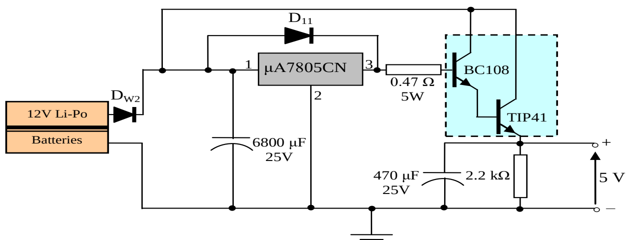

Fig. 9: The circuit diagram of the proposed stabilized power supply unit.

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 Fig. 3 and Fig. 4. 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.

3.3 Architecture of the HC-SR04 Ultrasonic Sensor

An ultrasonic sensor is a device that is capable of measuring the distance to an object by using sound waves as depicted in Fig. 5(a) and (b) [26, 27]. It measures by sending a sound wave at a specific frequency and listening for that sound wave

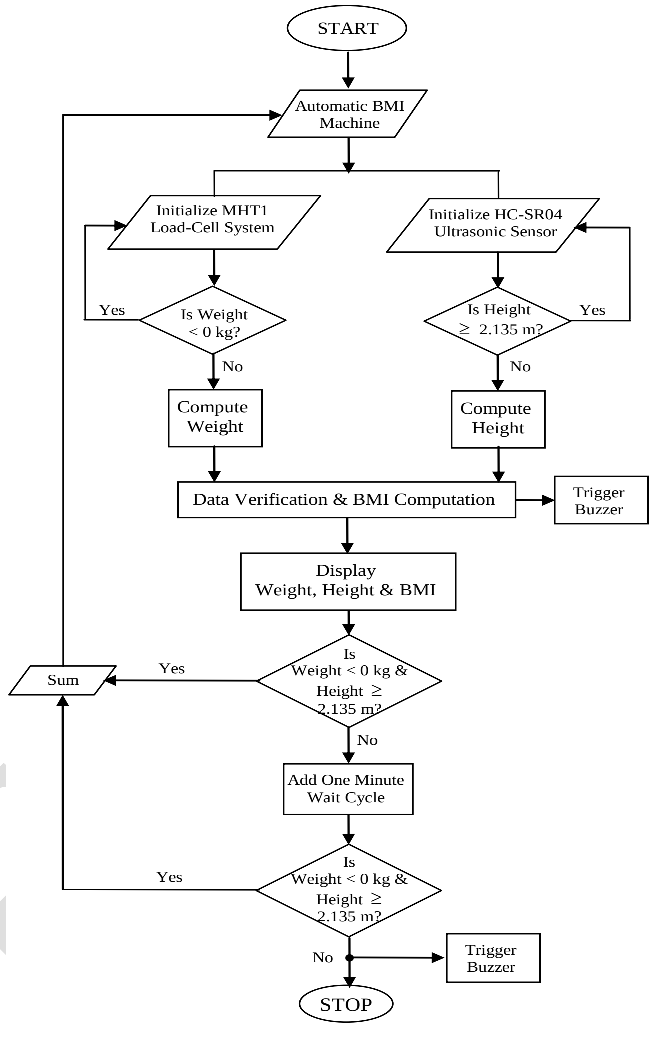

Fig. 10: The flowchart for the operation of the automatic BMI machine.

to bounce back. By recording the elapsed time between the sound wave being generated and sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object.

The HC-SR04 module is a four-pin sensor as shown in Fig. 6 [27]. Two pins ensure the power supply whereas one pins is for transmission and one for echo reception. It works on a 5 V voltage supply. The ultrasonic sensor of Fig. 6 has both transmitter and receiver on the same chip as illustrated in Fig. 5. When given a high pulse to the transmit pin of the sensor, it triggers a chirp signal, which get reflected back from the object and received by the echo pin.

3.4 Design of an Automatic Power Supply Module

It has been discussed in Section 3.2 using the block diagram of Fig. 4 that for the proper operation of the proposed low-cost automatic BMI machine, the Arduino Mega 2560 development board [28] and other components require 12-V while the HX711 load-cell amplifier module requires 5-V to avoid oscillation during loading.

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 Fig. 7 while the

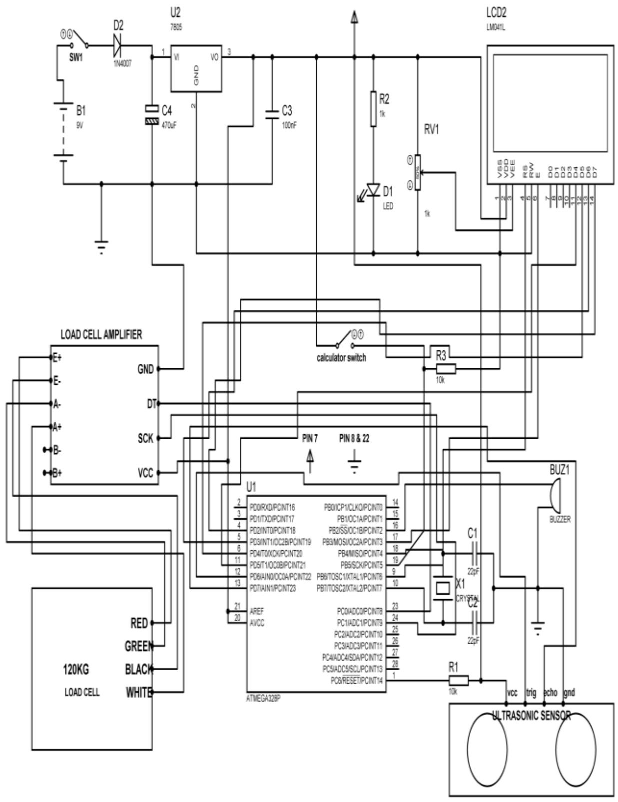

Fig. 11: The complete circuit diagram of the proposed automatic BMI machine.

(a) (b)

Fig. 12: The proposed automatic BMI machine: (a) shows the isometric view and (b) BMI measurement with the BMI machine.

circuit diagrams of the stabilized power supply unit (SPSU) and battery-powered 5-V SPSU in Fig. 7 are shown in Fig. 8 and Fig. 9 respectively [29]. As it can be seen in Fig. 7, 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 Fig. 12 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. TESTING AND VALIDATION

The principle of operation of the proposed low-cost automatic BMI machine is illustrated in the flowchart shown in Fig. 10. As shown in Fig. 10, 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 [30].

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) and height (HC-SR04 sensor) measurement systems before a new BMI measurement can be taken.

The complete block circuit diagram schematic showing all the system components for the proposed low-cost automatic BMI machine is shown in Fig. 11.

5. RESULTS AND DISCUSSIONS

The designed, developed and assembled low-cost automated BMI machine is shown in Fig. 12(a) while the operational demonstration of the machine for a sample BMI measurement of an individual (subject) is shown in Fig. 12(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 – 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,

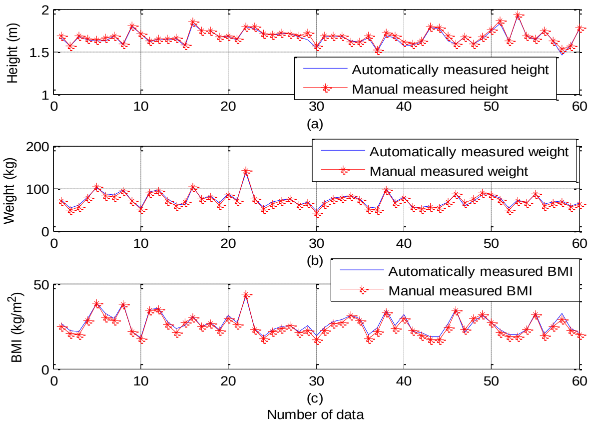

Fig. 13: Comparison of automatic BMI machine and manual measurements: (a) height, (b) weight, and (c) BMI.

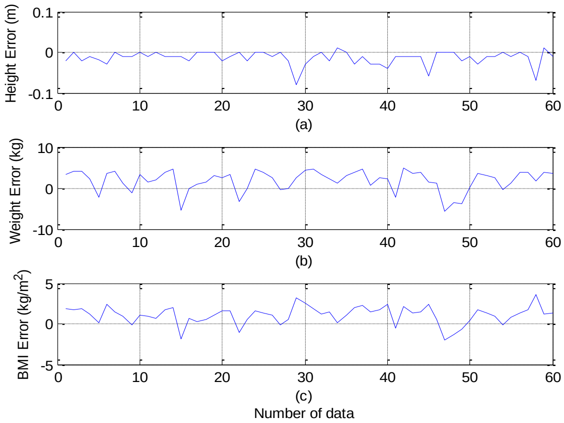

Fig. 14: Measurement errors between automatic BMI machine and manual measurements: (a) height, (b) weight, and (c) BMI.

weight and BMI are shown in Fig. 13 while their corresponding errors are shown in Fig. 14. The close matching of these measurements are evident in Fig. 13 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 accordingly in Table 3. According to WHO, healthy subjects 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 3.

According to Table 1 and the results shown in Table 3, 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 3 reveals that a 36 years old male subject on serial number 10 has a BMI of 18.3988kg/m^2 with a height of 1.71 meters and a weight of 53.8kg. Another 17 years old female subject on serial number 43 has a BMI of 18.4951kg/m^2 with a height of 1.78 meters and a weight of 58.6kg as well as the second 16 years old female subject on serial number 44 has a BMI of 18.4813kg/m^2 with a height of 1.77 meters and a weight of 57.9kg. 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?

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 137.1kg 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 45.8kg 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 73.1kg 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.

6. CONCLUSION

A body mass index (BMI) machine has been successfully designed, constructed, tested, 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. The BMI machine has been constructed using materials sourced from local Nigerian markets.

The constructed BMI machine can 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.

Table 3: Verification of automatic 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
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

S/N	Years	Sex	Height	Weight	BMI	Risk of Co-Morbidity
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

Furthermore, although the MHT1 load-cell can 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.

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APPENDIX A: SOFTWARE AND PROGRAM CODE FOR THE BMI MACHINE

```
#include <LiquidCrystal.h>
//              (RS, E, D4, D5, D6, D7)
LiquidCrystal lcd(12, 11, 5, 4, 3, 2)
int pingPin = 7;
int inPin = 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);
 // 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("                 ");
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 :");
 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);}
```