COVID-19 Management Requires Self-Sufficiency of Nations During Lockdown: Local Development of Body Mass Index Machine

Abdul Rasak Zubair, Isabella Ifeanyichukwu Ojiodu, Bolaji Olaide Abideen
Department of Electrical and Electronic Engineering, University of Ibadan, Ibadan, Nigeria

***Abstract*—There is increasing demand for biomedical devices. The demand for local design and production of these devices has become necessary most especially during the COVID-19 pandemic. Medical devices and facilities are overwhelmed in developed countries as there are more and more patients. Countries are in lockdown with their borders and international airports closed. Importing these devices become very difficult. The developing countries need to start looking inward and encourage local design, construction and fabrication of biomedical devices. The body mass index (BMI) is a measure of relative weight based on an individual's mass and height. BMI provides a simple numeric measure of a person's thickness or thinness. Obesity and overweight are associated with an amplified risk of diseases such as hypertension, diabetes and other forms of ailment. BMI monitoring is therefore essential in public health.The development of a Body Mass Index (BMI) machine is presented. The BMI machine has the mechanical hardware which constitutes the mechanical frame or stand, the electronic hardware which contains the transducers circuitry and control and the software housed in a microcontroller which serves as the central processing unit. Four load cells based sensor is used as weight transducer while of ultrasonic based sensor is employed as height transducer. The BMI machines measures the height and the weight of a patient and computes the patient's body mass index as the ratio weight to square of the height. The height measurements were compared and calibrated against measurements made by standard Tape Rule. The weight measurements were compared and calibrated against standard weights. Maximum percentage errors recorded are less than 1%, 2% and 6% for weight, height and Body Mass Index respectively. The height, weight and body mass index measurements by the BMI machine are found to be sufficiently accurate.**

Keywords—Self-sufficiency; Biomedical devices;Body mass index; transducers; Obesity; Public health

I. INTRODUCTION

The need for medical attention has increased as a result of change in diet, lifestyle and other factors, alongside increasing population. There is increasing demand for biomedical devices which are easy to operate, non-invasive, save, non-hazardous, accurate and consistent in measurement, reliable, fast, affordable, easy to maintain and suitable for patients' monitoring, diagnosis and treatment most especially in developing countries. The demand for local design and production of these devices has become necessary most especially during the COVID-19 pandemic. During the pandemic, there are more patients to care for. Even developed countries do not have adequate biomedical devices. Their medical devices and facilities are overwhelmed. Countries are in lockdown with their borders and international airports closed [1,2,3,4,5]. Importing these devices become very difficult. The developing countries need to start looking inward and encourage local design, construction and fabrication of biomedical devices [6].

Before 1980, doctors generally used weight-for-height tables; one for men and one for women that included ranges of body weights for each inch of height. These tables were limited because they were based on weight alone, rather than body composition. Body Mass Index (BMI) became an international standard for obesity measurement in the 1980s. The public learned about BMI in the late 1990s, when the government launched an initiative to encourage healthy eating and exercise [7,8].

The body mass index (BMI) is a measure of relative weight based on an individual's mass and height. In the nineteenth century, a Belgian statistician named AdolpheQuetelet came up with the Quetelet Index of Obesity, which measured obesity by dividing a person's weight (in kilograms) by the square of his or her height (in inches) [7,9].

While the formula previously called the Quetelet Index for BMI dates to the beginning of the 19th century, the new term "body mass index" for the ratio and its popularity date to a paper published in the July edition of 1972 in the Journal of Chronic Diseases by Ancel Keys, which found the BMI to be the best proxy for body fat percentage among ratios of weight and height [10]. BMI provides a simple numeric measure of a person's thickness or thinness, allowing health professionals to discuss overweight and underweight problems more objectively with their patients.

The World Health Organization states that "obesity is a condition of abnormal or excessive fat accumulation in adipose tissue to the extent that the health may be impaired". It is widely acknowledged that being overweight is associated with an amplified risk of disease such as hypertension, diabetes and other forms of ailment, particularly if body fat is deposited within the abdomen, as suggested by a high waist-circumference measurement [11]. BMI, which is calculated as weight (kg) divided by height squared (m^2), was chosen as a simple measurement of body weight in relation to height. While increases in both body fat and lean tissue cause increments in BMI, relationships between body weight and health are conventionally expressed in terms of BMI rather than body fat [12,13,14].

Nowadays, Body Mass Index (BMI) is calculated manually through measuring tape and weighing scale. There are charts and graphs that show the ratio of proper weight according to height measurement to determine whether a person has too much body fat. It takes time and effort to calculate the body fat. The calculation of BMI is done in the hospitals and is used by health professionals to determine healthy weights and risky weights. It is also used by schools to diagnose students in their various weight classification (Underweight, Normal, Overweight, and Obese) when conducting feeding programs [15].

Some universities use this calculation in physical examination and for medical purposes. Fitness gyms also use BMI calculations to evaluate their clients and help them reach their proper weight. Pediatricians employ BMI percentile screening for health monitoring of children, teenagers and young adults. Parents often wondered if their children are overweight, underweight or just right. Using body mass index calculator can figure out if the child is in an appropriate weight for his or her height.

BMI provides a good indicator for levels of body fat, and it is known that having a BMI that is either too low or too high is associated with an increased risk of ill health in life [12,13,14].

The BMI-for-age charts for boys and girls aged 2 to 20 years are shown in Fig. 1. The recommended BMI-for-age cut-offs for teens are presented in Table I. Overweight rather than obesity is the term preferred for describing children and adolescents with a BMI-for-age equal to or greater than the 95th percentile of BMI-for-age. The cut-off for underweight of less than the 5th percentile is based on recommendations by the World Health Organization Expert Committee on Physical Status on 1996 [16,17,18,19,20,21].

TABLE I. BMI-FOR-AGE CUT-OFFS FOR TEENS [16]

S/N	***Range***	***Description***
1	≥ 95th percentile	Overweight
2	85th to < 95th percentile	Risk of overweight
3	5th to <85th percentile	Normal
4	< 5th percentile	Underweight

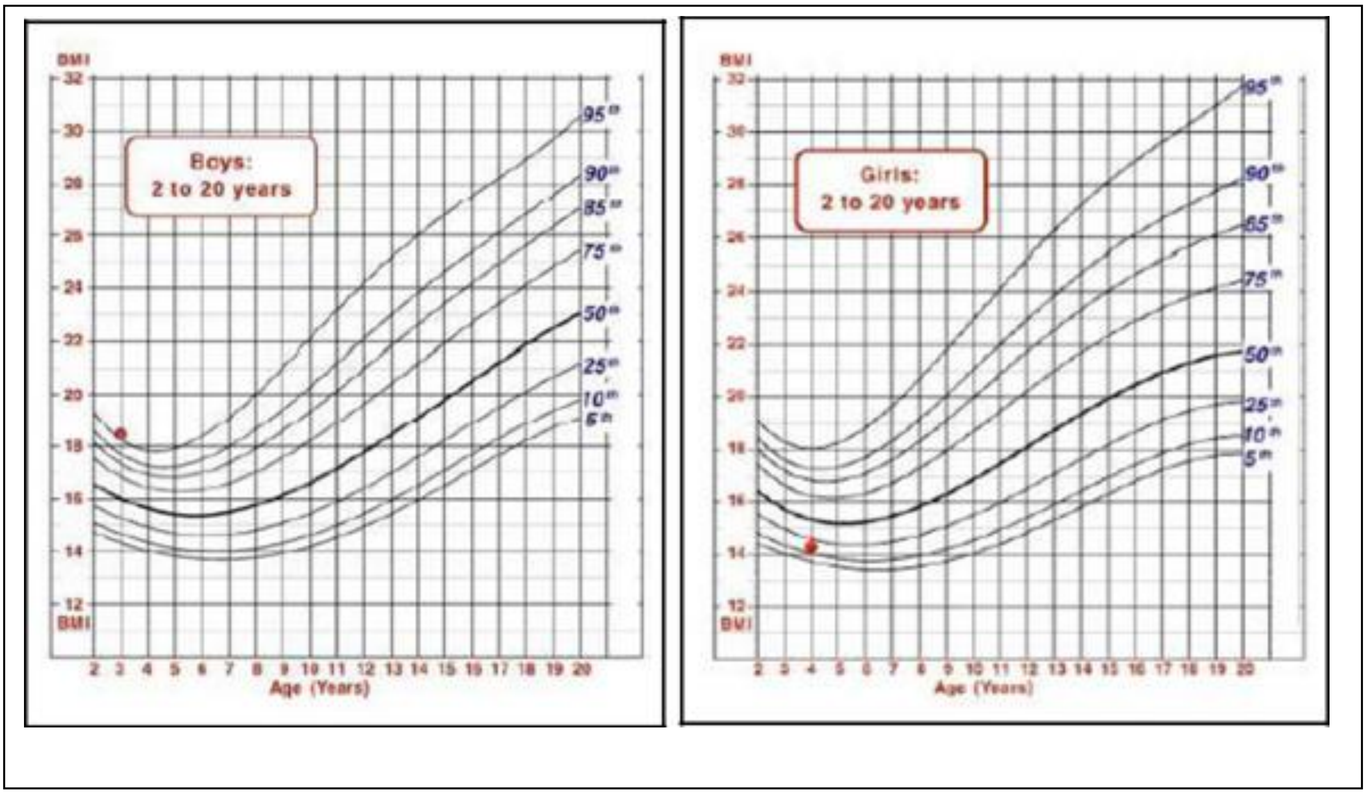


Fig. 1. *BMI-for-Age Growth Charts for 2-20 years old [16]*

For adults, BMI is not age or gender specific and the classification of overweight and underweight is not the same as that for children and adolescents. For adults, overweight and underweight categories are defined by fixed BMI cut-points as shown in Fig. 2. Clinical guidelines established in 1998 by the National Heart, Lung, and Blood Institute is shown in Table II. Fig. 3 shows classification of BMI for various level of obesity for adults [19,20,22].

TABLE II. BMI-FOR-AGE CUT-OFFS FOR TEENS [19,20]

S/N	***Range***	***Description***
1	BMI less than 18.5	Underweight
2	BMI of 18.5 through 24.9	Normal
3	BMI of 25.0 through 29.9	Overweight
4	BMI of 30.0 and above	Obese

II. MATERIALS AND METHODS

The proposed Body Mass Index (BMI) machine has three subsystems. These subsystems are the Mechanical Hardware, the Electronic Hardware and the Software.

A. The Mechanical Hardware

The mechanical hardware is the BMI machine frame. A base was created for the Weight Scale for measurement of Weight and a stand was made for the ultrasonic sensor for measuring the height of the user or patient. The various views and the image of the mechanical frame are shown in Figs. 4, 5, and 6. The components of the mechanical frame are the Stand / Stem, the BMI gadget holder, the Ultrasonic Sensor Holder, the Reflector and the Base of the system as illustrated in Fig. 4(a).

The Stand / Stem is the backbone of the system to which all other parts are joined. It is made of aluminium. The BMI gadget holder is located at the middle of the Stand and provides placement for the BMI gadget/ circuitry board. The BMI gadget holder is made of iron. The Ultrasonic Sensor holder is located at the top of the Stand and provides placement for the ultrasonic sensor circuitry and has two holes for the protruding of the trigger and echo of the sensor. The Ultrasonic Sensor holder is also made of iron.

The reflector is a movable part of the system that is adjusted to the height of the user or the patient to be measured. While experimenting with the ultrasonic sensor, it was noticed that human hair affects the height measurement since it is black and would absorb all the rays from the sensor hence the need for a reflector. It is made of polished wood. The base of the System is useful for the placement of the weighing scale and is located at the foot of the Stand and is made of layered wood. The Solid, Wireframe Isometric Views of the mechanical frame are shown in Fig. 4. Fig. 5 shows the two dimensional wireframe and realistic top perspective views. The left and right perspective views are presented in Fig. 6.

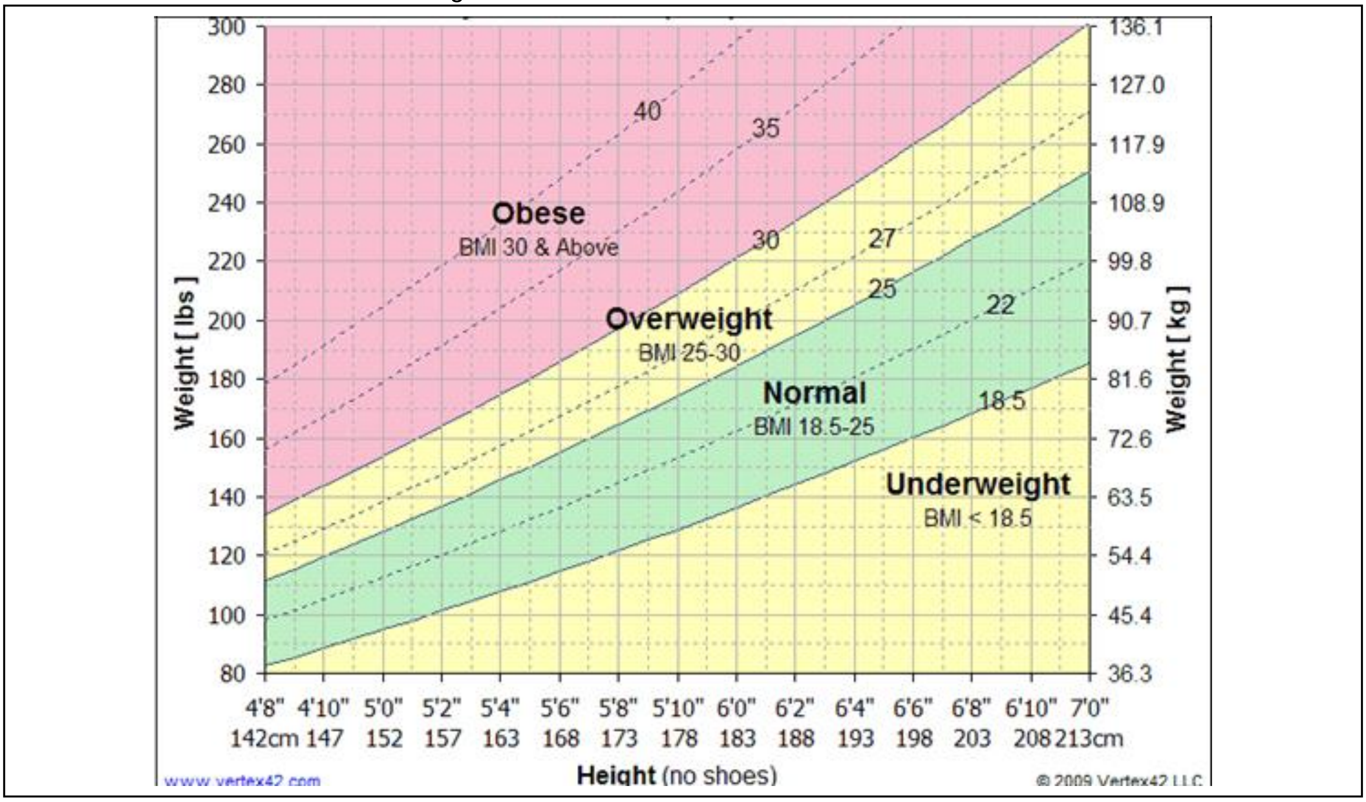


Fig. 2. *BMI-for-Age Growth Charts for Adults [19,20]*

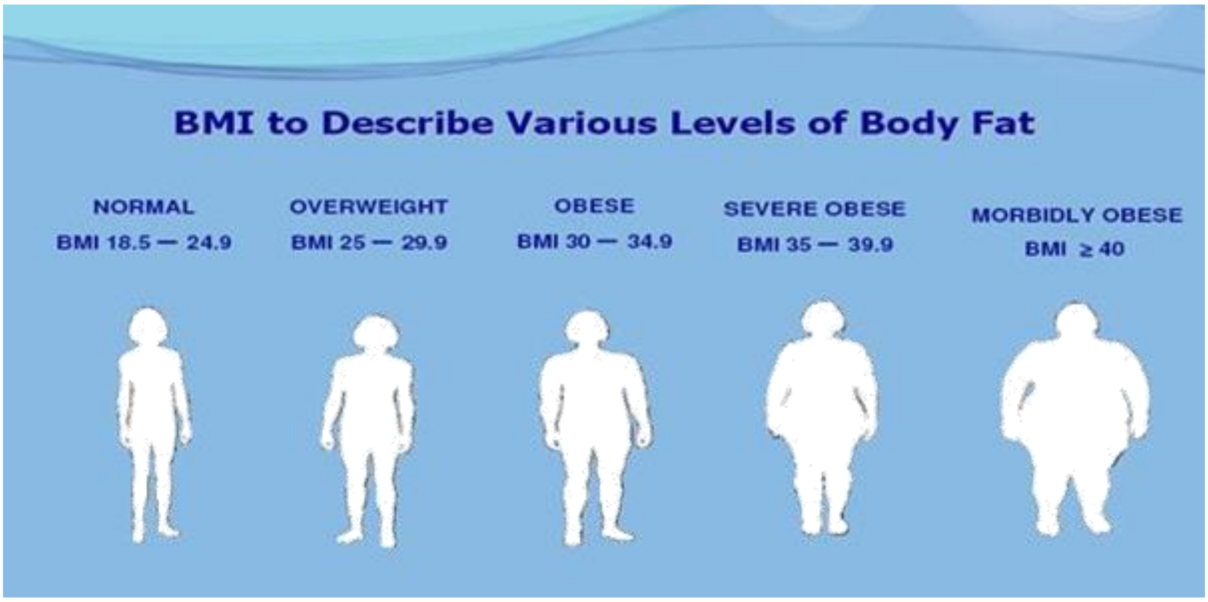


Fig. 3. *A diagram of various Obesity and their BMI Value [19,20]*

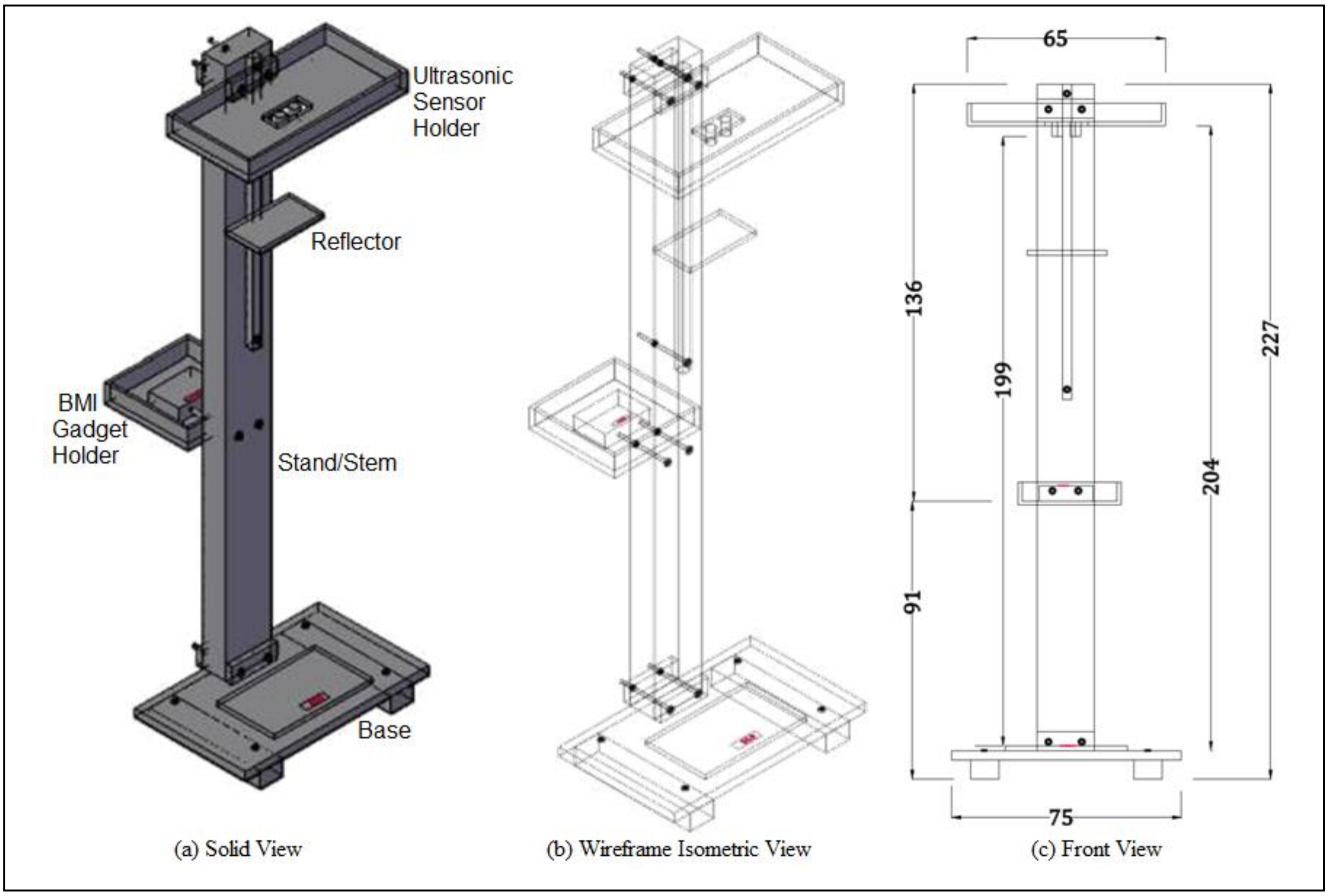
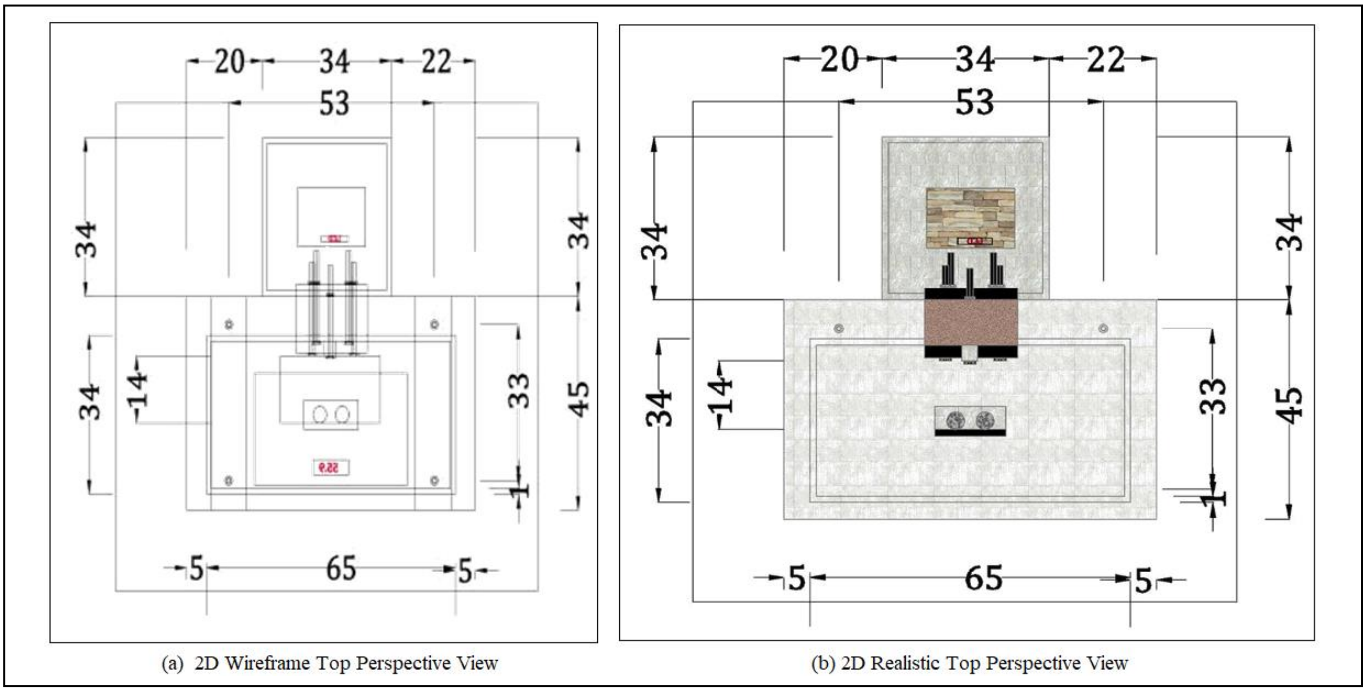
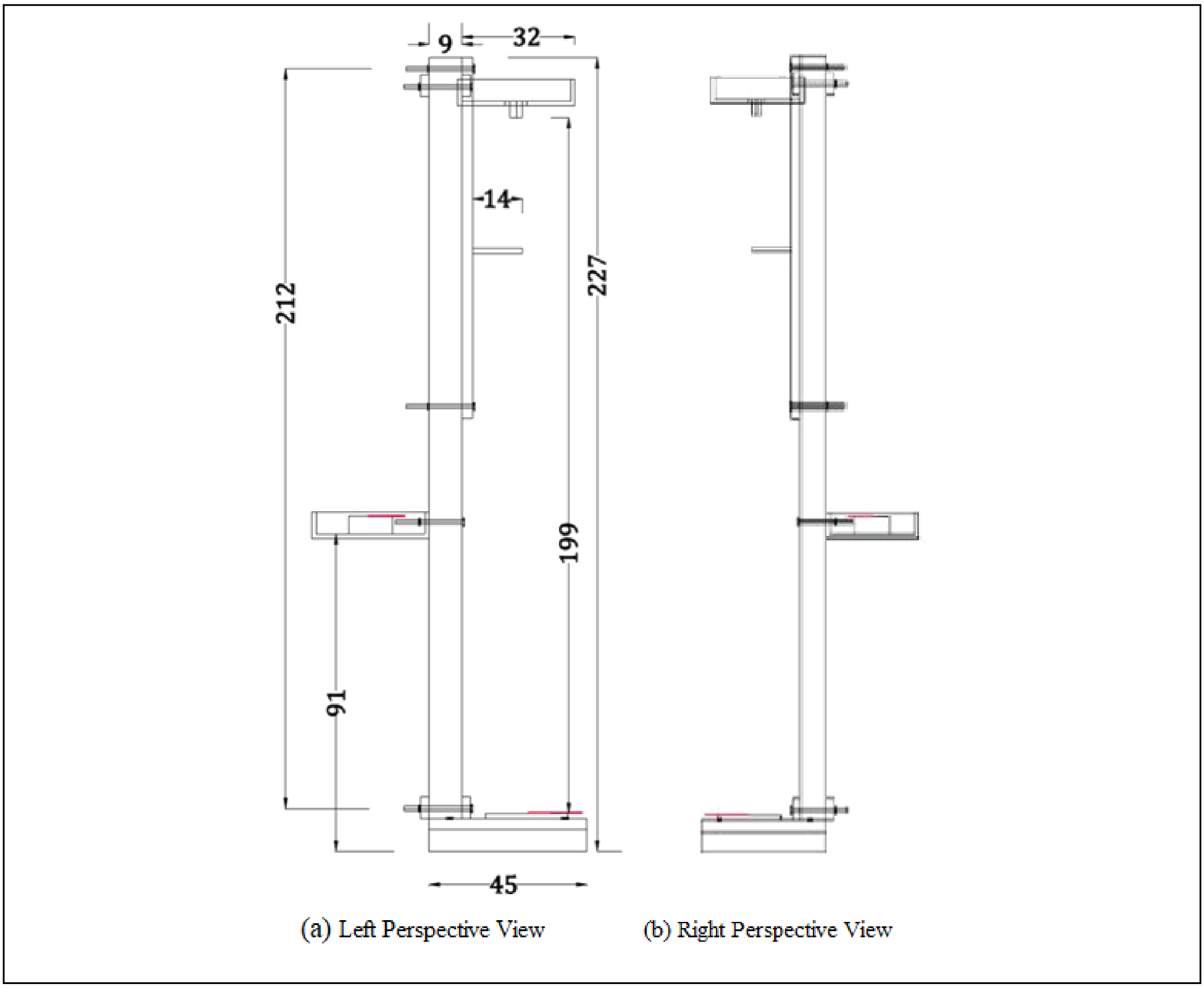


Fig. 4. *Solid, Wireframe Isometric and Front Views of the Mechanical Frame*



(a) 2D Wireframe Top Perspective View (b) 2D Realistic Top Perspective View

Fig. 5. *2D Wireframe and Realistic Top Perspective Views*



(a) Left Perspective View (b) Right Perspective View

Fig. 6. *Left and Right Perspective Views*

B. *The BMI Gadget*

The BMI Gadget is the major electronic hardware part of the machine because it is the one that controls the height and weight transducers and processes the signals from the transducers. It also computes, classifies and displays the Body Mass Index. Fig. 7 shows the block diagram of the BMI Gadget. The signal from the Weight Transducer is first amplified by HX711 amplifier. The amplified Weight Transducer signal and the Height Transducer signal are further processed by the microcontroller (Arduina Nano) which has been programmed using the Arduino IDE to perform the computation of the BMI. The microcontroller output information via the LCD Display, Buzzer and LED Indicators. The Display shows the height, the weight and the BMI results. The LED shows the range of the BMI (Underweight, Normal, Overweight, Obese).

The Power Supply Unit of Fig. 8 steps down the mains ac supply and generate a regulated 5 V dc supply required by the transducers and other electronic components.

The input stage consists of four load cells sensor which are used for determining the weight of the user or patient and Hx711 amplifier which amplifiers the load cells output for interfacing with the Arduino board. This stage also involves the use of ultrasonic sensors for determining the height of the user. The output of the two sensors namely the weight from the load cells and the height from the ultrasonic sensors are interfaced with the microcontroller in this case the ArduinoNano which computes the Body Mass Index of user.

Ultrasonic Sensors are non – contact transducers which measures distance using the principle of ultrasonic wave technologies [23,24,25]. Ultrasonic waves are sound waves transmitted above the human-detectable frequency range, usually above 20,000 Hz. Figure 9 shows ultrasonic wave incidence and reflection principle.

Most ultrasonic sensors are transceivers because they can both sense and transmit as shown in Fig. 10. The ultrasonic sensor works on the principle of sending ultrasonic waves to the space medium, when the ultrasonic wave meets any object, it is reflected back to the ultrasonic sensor which then computes the corresponding distance of the object based on the duration of travel of the ultrasonic wave.

The ultrasonic sensor uses two pins which are the Trigger and Echo pins shown in Fig. 10 to measure distance from the object. The Trigger transmits ultrasonic wave to the medium which is being reflected by the object and received by the echo pin. The Echo pin is turned on for the duration of the time taken by the wave transmitted and received. To compute accurately the height of the user, the distance from the head of the user to the ultrasonic sensor has to be deducted from the maximum reference height of 200cm.

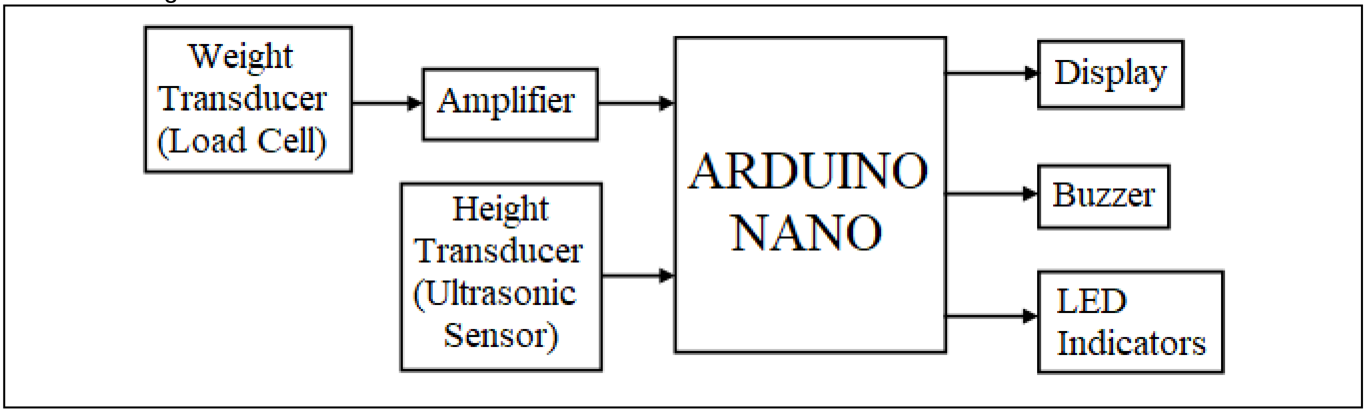


Fig. 7. *Block Diagram of the BMI Gadget*

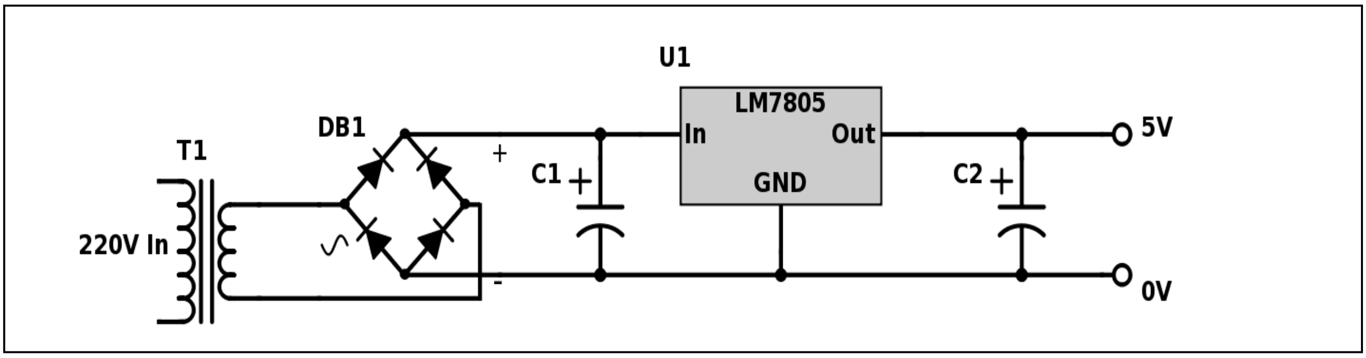


Fig. 8. *Power Supply Unit*

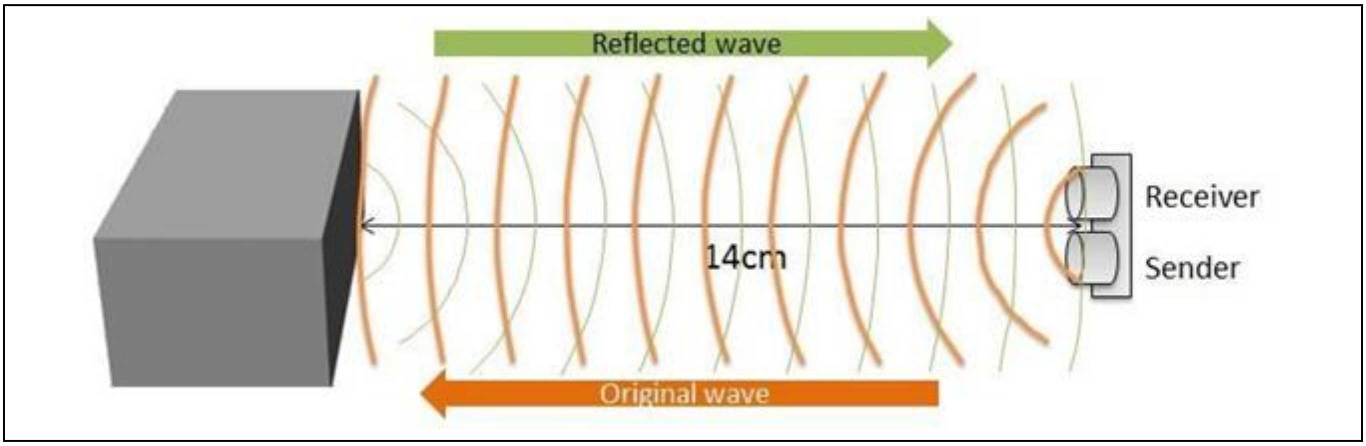


Fig. 9. *Ultrasonic Wave Incidence and Reflection (Echo) Principle of ultrasonic sensor*

Fig. 10. *Ultrasonic Sensor (HC-SR04) for distance and height Measurement*

A load cell is a type of transducer, specifically a force transducer. It converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured. As the force applied to the load cell increases, the electrical signal increases proportionally [26,27]. When properly designed and used, they are very accurate and reliable sensors. Load cells are applied in several different fields for weighing objects. Among many other things, food, vehicles, and animals are weighed daily with load cells. The most common types of load cell used are hydraulic, pneumatic, and strain gauge.

Strain gauge load cells are the most common in industry. These load cells are particularly stiff, have very good resonance values, and tend to have long life cycles in application. The strain gauge resistance changes according to the deformation of the spring element. Strain is the deformation that occurs in a material when it is submitted to a stress. Stress is force acting on a specific area of a material. When stress is applied to conductors, there is variation in electrical resistance.

When a spring is subjected to mechanical stress, it contracts or expands. The spring is used in conjunction with strain gauges that vary in electrical resistance when under stress. To measure the stress, strain gauges are attached to the spring element surface that contracts or expands and the mechanical changes in the surface are transmitted to the gauge. The intensity of the electrical resistance variation in the strain gauges is proportional to the intensity of the applied force. Fig. 11 shows a 3-wire Load Cell.

In most cases, four strain gauges are used to obtain maximum sensitivity and temperature compensation. In this work, four quantities of the load cell of Fig. 11 are used. They are configured as a Wheatstone bridge to produce just four wires (full drive) as shown in Fig. 12. E+ AND E- in Fig. 12 are the DC power supply to the Load cell while S+ and S- are the output signal terminals.

Two of the gauges are usually in tension; these two gauges are represented as T1 and T2. The remaining two gauges are in compression and are represented as C1 and C2.

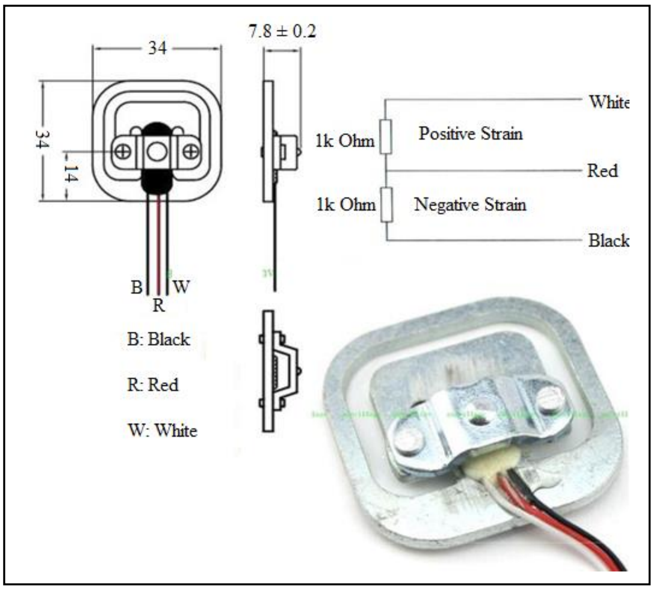


Fig. 11. *A 3-wire Load Cell for detecting force, weight and strain*

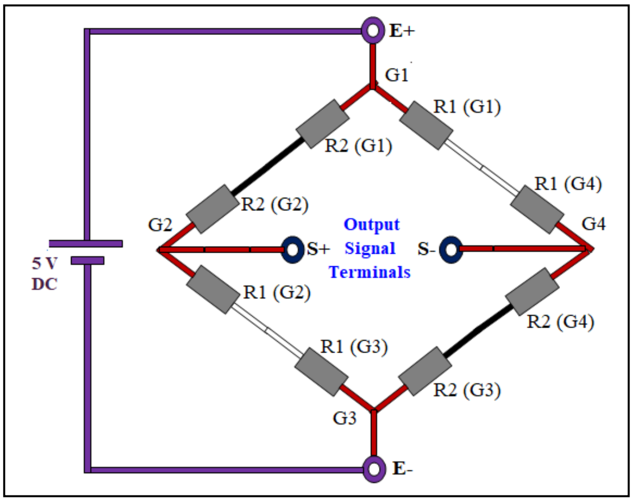


Fig. 12. *Arrangement of four 3 wire load cells to form bridge network to generate four wires load cell*

Gauges are mounted in areas that exhibit strain in compression or tension. When a weight (load) is applied to the load cell, gauges C1 and C2 compress and their resistances decrease. Simultaneously, gauges T1 and T2 are stretched and their resistances increase. The changes in resistances cause more current to flow through C1 and C2 and less current to flow through T1 and T2. Thus a potential difference appears across the terminals of the load cell. The gauges are mounted in a differential bridge to enhance measurement accuracy. When weight is applied, the strain changes the electrical resistances of the gauges in proportion to the weight (load).

The Arduino comes in various packages such as Arduino Uno, Arduino Nano, ArduinoPromini, and ArduinoLilipad. The Arduino Nano of Fig. 13 was selected as the central processing unit for the BMI. Arduino NANO can be powered using a mini-b USB cable. The Arduino NANO has 10 Digital Input / Output pins, 5 Analog Input pins and 3 Power pins (5V, 3.3V, & GND). For communication, the Arduino NANO uses the Universal Asynchronous Receiver and Transmitter (UART), the Inter Integrated Communication (I2C) and the Serial Parallel Interface Communication (SPI).

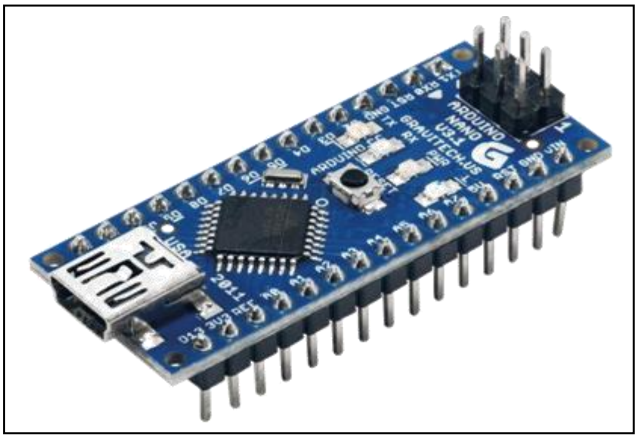


Fig. 13. *Arduino Nano board*

The HX711 Load Cell Amplifier is a 24 high-precision Analog to Digital Converter (ADC) with programmable gain of 128 integrated amplifiers [26]. The output signal from the load cell is passed to the microcontroller via the amplifier as illustrated in Fig. 14.

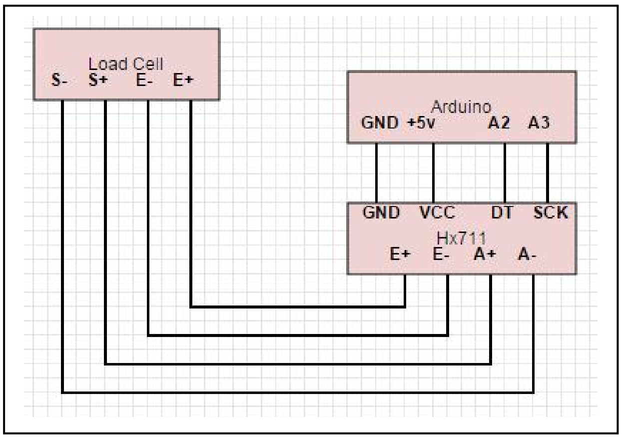


Fig. 14. *Arrangement of four 3 wire load cells to form bridge network to generate four wires load cell*

The Liquid Crystal Display (LCD) of Fig. 15 is used to show the visual text of measurements taken from the inputs (Load cells for weight and ultrasonic sensor for height) and the BMI Computation made by the central processing unit (the Arduino Nano). The Liquid crystal display (LCD) is a flat panel display that uses light modulating properties of liquid crystals.

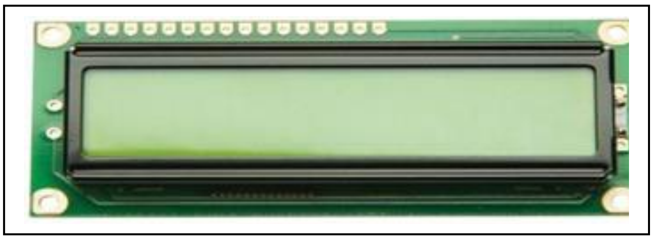


Fig. 15. *Liquid Crystal Display (HD 44780)*

The LCD Backpack of Fig. 16 is a useful interface between the Arduino Nano and the LCD Display. The use of this I2C interface allows the LCD to be controlled directly from a microcontroller. It simplifies wiring.

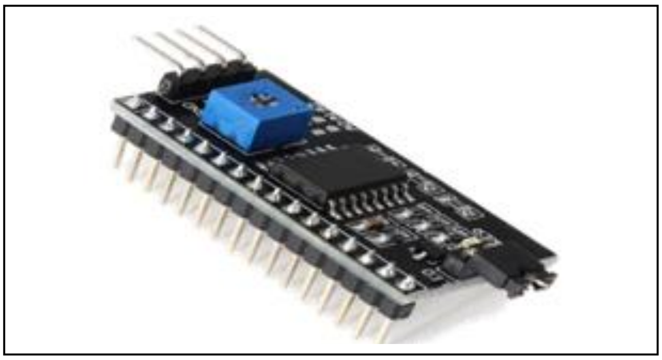


Fig. 16. *I2C Backpack (Serial to Parallel Converter)*

A buzzer or beeper of Fig. 17 is an audio signaling device, which may be mechanical, electromechanical, or piezoelectric. Typical uses of buzzers and beepers include alarm devices, timers, and confirmation of user input such as a mouse click or keystroke. The audio which is the buzzer shows warning indication when there is underweight, overweight, or obese.

Fig. 17. *Buzzer for Audio warnings*

A light-emitting diode (LED) is a p–n junction diode, which emits light when activated. The LED are used to indicate the status of the BMI Computation result which is either underweight, normal, overweight and obese. The complete circuit diagram is presented in Fig. 18.

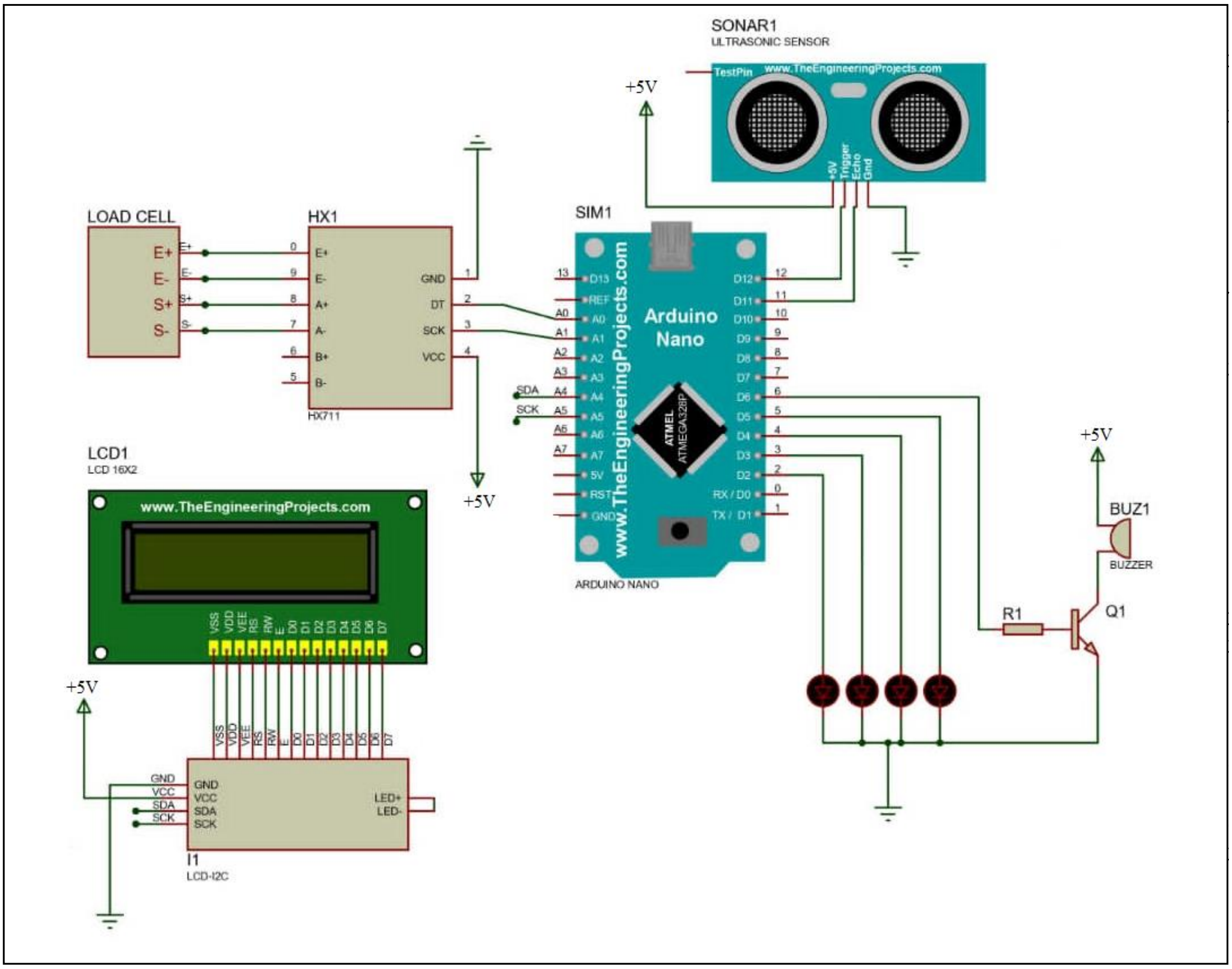


Fig. 18. *The complete circuit diagram of the BMI machine*

C. *The Software*

The software program for the BMI was developed using the Arduino Sketch program, which is a C Language IDE. The software receives information from both the Weight Transducer and the Height Transducer and computes the BMI. The software sends required information to the LCD Display, the LED and the Buzzer.

D. *Calibration*

The height measurements were compared and calibrated against measurements made by a standard Tape Rule. During the computation of the height, the maximum height used for the mechanical frame work was 200cm. The weighing scale occupies little height which is deducted from the maximum reference height (200cm). The weight measurements were compared and calibrated against standard weights. The calibrations were done in the arduino software. The software was adjusted in accordance with the standard measurements.

III. TESTS AND RESULTS

The developed BMI machine is referred to as the Device Under Test (DUT). DUT was subjected to accuracy and performance tests.

A. *Accuracy*

The weight measurements by the DUT are compared with standard weights as shown in Table III. The error is less or equal to ±0.75%. Thus the accuracy is satisfactory.

The height measurements by the DUT are compared with height measurements by Tape Rule as presented in Table IV. The accuracy is satisfactory as the error is less or equal to ±0.3%.

B. *Performance Test*

The height and weight measurements by the BMI DUT are compared with those of a Tape Rule and a Bathroom Scale respectively as presented in Tables V and VI. The BMI computation by BMI DUT and BMI manual computation are also compared in Table VII.

Fig. 19 compares the developed BMI machine weight measurements with the Bathroom Scale weight measurements. Fig. 20 shows the height measurements obtained with Tape Rule and those obtained with the developed BMI machine. Fig. 21 compares the Body Mass Index values obtained with the BMI machine with those obtained by manual computation. Maximum percentage errors recorded are less than 1%, 2% and 6% for weight, height and Body Mass Index respectively. The Body Mass Index is the weight divided by the square of the height; hence the error recorded with the Body Mass Index is higher than those of the weight and the height.

TABLE III. WEIGHT MEASUREMENTS ACCURACY TEST RESULTS

S/N	*Standard Weight (kg)*	*DUT Weight (kg)*	*Error (kg)*	*Error %*
1	1	0.9925	-0.0075	-0.750
2	10	9.925	-0.0750	-0.750
3	50	49.625	-0.3750	-0.750
4	75	74.438	-0.5620	-0.750
5	100	99.25	-0.7500	-0.750

TABLE IV. HEIGHT MEASUREMENTS ACCURACY TEST RESULTS

S/N	*Tape Rule Height (cm)*	*DUT Height (cm)*	*Error (cm)*	*Error %*
1	10	9.97	-0.03	-0.3
2	20	19.94	-0.06	-0.3
3	30	30.09	0.09	0.3

S/N	*Tape Rule Height (cm)*	*DUT Height (cm)*	*Error (cm)*	*Error %*
4	40	39.87	-0.12	-0.3
5	50	50.15	0.15	0.3
6	60	59.82	-0.18	-0.3
7	70	69.79	-0.21	-0.3
8	80	79.76	-0.24	-0.3
9	90	89.73	-0.27	-0.3
10	100	99.70	-0.30	-0.3
11	110	110.33	0.33	0.3
12	120	120.36	0.36	0.3
13	130	129.61	-0.39	-0.3
14	140	139.58	-0.42	-0.3
15	150	149.55	-0.45	-0.3
16	160	159.52	-0.48	-0.3
17	170	169.49	-0.51	-0.3
18	180	179.46	-0.54	-0.3
19	190	190.57	0.57	0.3
20	200	199.40	-0.60	-0.3

TABLE V. PERFORMANCE TEST RESULTS: HEIGHT

S/N	*Bath-room Scale Weight (kg)*	*DUT Weight (kg)*	*Error (kg)*	*Error %*
1	74.0	73.4	-0.60	-0.81
2	75.5	75.5	0.00	0.00
3	67.0	67.2	0.20	0.30
4	62.5	62.3	-0.20	-0.32
5	70.5	70.5	0.00	0.00
6	68.5	68.3	-0.20	-0.29

TABLE VI. PERFORMANCE TEST RESULTS: HEIGHT

S/N	*Tape Rule Height (m)*	*DUT Height (m)*	*Error (m)*	*Error %*
1	1.76	1.75	-0.01	-0.57
2	1.71	1.70	-0.01	-0.58
3	1.77	1.74	-0.03	-1.69
4	1.69	1.66	-0.03	-1.78
5	1.81	1.79	-0.02	-1.10
6	1.66	1.65	-0.01	-0.60

TABLE VII. PERFORMANCE TEST RESULTS: HEIGHT

S/N	***Manual BMI (kg/m^2)***	***DUT BMI (kg/m^2)***	***Error (kg/m^2)***	***Error %***
1	23.9	24.0	0.10	0.42
2	25.8	26.1	0.30	1.16
3	21.4	22.5	1.10	5.14
4	21.9	22.6	0.70	3.20
5	21.5	22.0	0.50	2.33
6	24.9	25.1	0.20	0.80

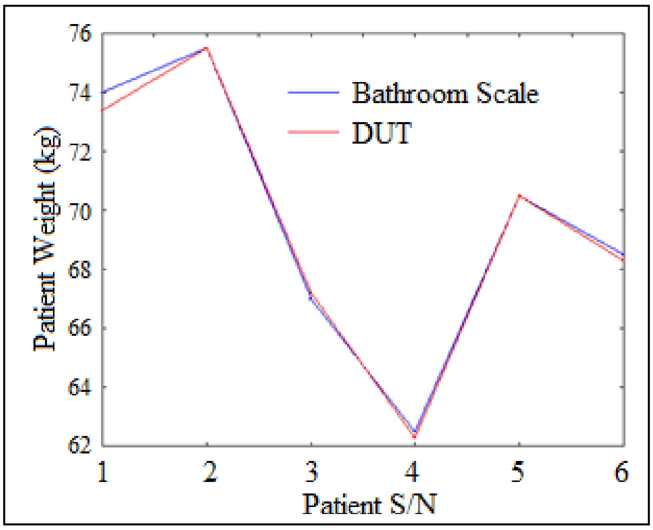


Fig. 19. *Comparison of weight measurements obtained with the BMI machine with those obtained with the Bathroom Scale*

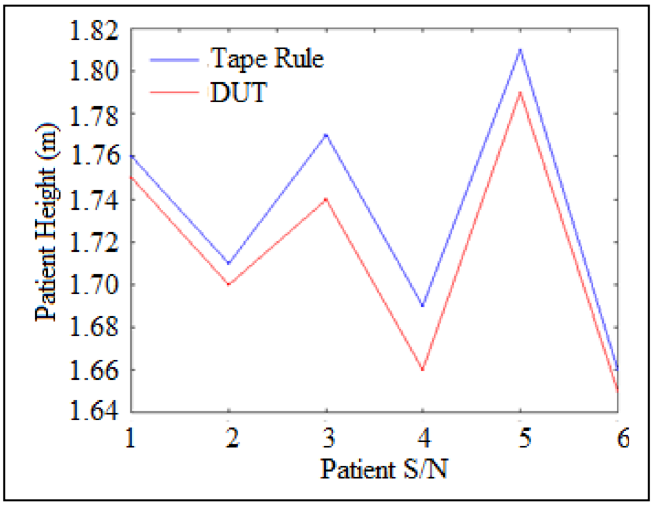


Fig. 20. *Comparison of weight measurements obtained with the BMI machine with those obtained with Tape Rule*

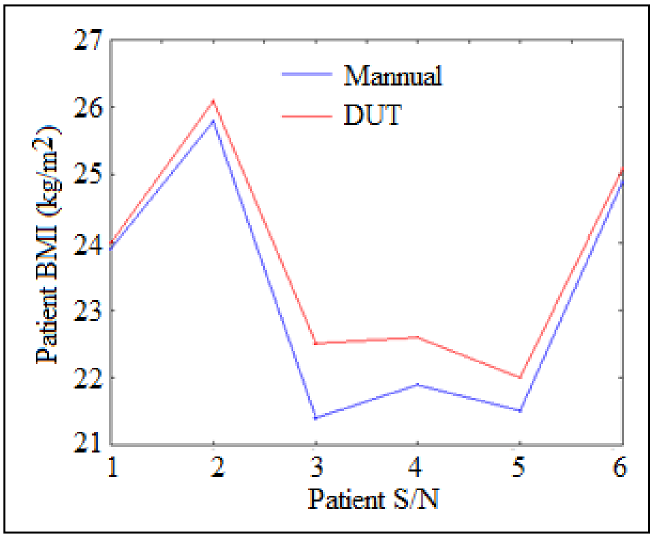


Fig. 21. *Comparison of mannually computed body mass index values with those obtained with DUT*

IV. CONCLUSION

A Body Mass Index Machine has been developed. The height, weight and body mass index measurements by the BMI machine are found to be sufficiently accurate. A nation does need to import simple biomedical devices which can be locally developed. Such local development with enhance the self-reliance and self sufficiency of nations when nations are locked down for COVID-19 or similar challenges. Such local development will also make economic use of local materials, create jobs and conserve scarce foreign currencies. Furthermore, the availability of the BMI machines will enable people to monitor and control their obesity which will reduce the health risk related to high biomedical index values like diabetes and hypertension.

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