

Development of an Automatic Body Mass Index Measurement Machine

¹Theophilus Ewetumo, ¹Kayode D. Adedayo, ^{*2}Yusuf B. Lawal, ³Abiodun T. Edun and ¹Joseph E. Orokhe

¹Department of Physics, Federal University of Technology, Akure, Ondo state, Nigeria

²Department of Physics, University of Africa, Toru-orua, Bayelsa State, Nigeria

³Department of Science Laboratory Technology, Moshood Abiola Polytechnic, Ogun State, Nigeria

ewetheo66@gmail.com | kbadedayo@futa.edu.ng | lawalyusuf.b@gmail.com | edunbdn@yahoo.com | jeorokhe@futa.edu.ng

Abstract - The potential occurrence of certain illnesses can be easily diagnosed through measurements of some health indicators. One of such parameters is the Body Mass Index (BMI). BMI is simply the ratio of mass (kg) of a body to the square of its height (m²). This research presents the design and construction of an automated BMI measurement machine for medical purposes. It consists of three major units: the weighing unit (5 – 200 kg); height-measuring unit (0.02 – 2 m) and the processing unit. The weighing unit is made up of load button cell and load cell amplifier while the height-measuring unit consists of ultrasonic sensor. The analog differential output voltage from load cell is connected to Arduino microcontroller via a Programmable Gain Amplifier (PGA) integrated with Analogue-to-Digital Converter (ADC). The two units are connected to an open source Arduino Uno which computes mass-to-body ratio and sends the output results (mass, height and BMI) to the liquid crystal display (LCD). The weighing system was calibrated against a precision digital weighing system and it gave a correlation of 0.99. The height measurement was also compared with manual height measurement using a tape rule which gave a correlation of 0.97. The developed Instrument is cost effective and has high positive correlation with the standards (weighing scale and tape rule), it is therefore recommended for the measurement of weight, height and BMI.

Keywords - load button cell, load cell amplifier, ultrasonic, body mass index, Arduino Uno

1 INTRODUCTION

The quest for the prevention and ultimately arrests of cardiovascular diseases is perhaps one of the most pressing concerns for the health experts around the world. Terminal ailments such as type II diabetes (diabetes mellitus), ischemic heart disease, stroke, hypertensive heart disease, osteoarthritis, cancers of the postmenopausal breast, colon, endometrium and kidney are all linked to cardiovascular dysfunction, which is also consequent upon excessive body fat. These non-communicable ailments have overtaken communicable diseases as major causes of untimely death worldwide. According to the World Health Organization, more than 38 million premature deaths per annum are attributable to these group of ailments, 82% of which occurs in the less developed countries (WHO, 2015). This is highly worrisome and calls for special attention to minimize the dominance rate.

Weight and height measurements are used to determine the state of the body such as underweight, normal weight, overweight and obese. Obesity results from an incorrect energy balance leading to an increased store of energy, mainly as fat (Micheal, 2013). The major factors that contribute to obesity include over-nutrition, physical inactivity, change of dietary habits, modernization, consumption of high fat, high carbohydrate foods, and in a minority of patients, a physical condition or metabolic disturbance. A BMI result less than 18.5 kgm⁻² is underweight, between 18.5 kgm⁻² to 24.9 kgm⁻² is normal, 25.0 kgm⁻² to 29.9 kgm⁻² is overweight and a reading of 30 kgm⁻² and above is obese. The risks of death are high for the overweight person (Michael, 2013). Body Mass Index (BMI) is currently being used by competent authorities as an index of obesity. In fact, BMI is used to categorize different classes of obesity, with class I, II and III being $30 \leq \text{BMI} < 35$, $35 \leq \text{BMI} < 40$, and $\text{BMI} \geq 40$, respectively (Laura, 2017). There are different appropriate BMI ranges for children and adults.

For instance, if a child or teen has a BMI very close to 30 kgm⁻², the child is certainly obese whereas BMI in this range potential risk of class I obesity (CDC, 2014). BMI of 18.5-25 is generally regarded as normal for all age groups. Measurement of BMI is actually aimed at assisting early childhood professionals in tackling the risk of obesity in young children. The vital role of BMI in analyzing human health status motivated the development of a low cost locally made automated BMI measurement machine.

BMI is the ratio of weight in kilogrammes to height in squared metres. BMI is used to assess weight status and to estimate a persons' risk of weight-related health problems. A BMI is relatively easy to carry out, inexpensive, non-invasive, quick to obtain and correlates with body fat (Nihiser *et al*, 2007). However, recent researches have shown that BMI is rather a poor indicator of percent of body fat. (Nuttall, 2015). In children and adolescents, BMI changes with age and sex. It increases proportionately with children's age. Therefore, BMI values must be plotted on a sex-specific growth curve to determine the percentile for sex and age in order to estimate the student's risk of weight-related health problems (State of Alaska, 2012).0

Using the gender-correct growth chart titled BMI-for-age, the student's age (to the nearest ¼ years) is plotted on the horizontal axis while the BMI value is on vertical axis. The point of intersection defines the student's BMI-for-age percentiles. The classification BMI-for-age percentile for children between 2-20 years old is shown in Table 1 (State of Alaska, 2012). Children whose weight classifications fall outside healthy weight range are at risk of a variety of health problems. Eating disorders such as anorexia, bulimia, and binge eating can result in both serious long-health problems and poor school performance (Carlene, 2014). Obese children are at increased risk of a number of chronic conditions including type 2 diabetes, hypertension, high cholesterol, asthma, certain forms of cancer and non-alcoholic steato-hepatities (fatty liver). Obese youths

*Corresponding Author

may also experience social stigmatization and discrimination, as well as psychological problems. Also, children and adolescent who are overweight and obese have an increased risk of being overweight or obese as adults (State of Alaska, 2009). For these purposes, it is important to keep monitoring BMI values especially in children and teens. According to many researchers, BMI does not give an exact measurement of total body fat but one thing that is clearly obtained is that, it is correlated with total body fat like other methods of body fat calculation such as dual energy x-ray absorptiometry and underwater weighing techniques (Mei, 2002; Garrow, 1985).

Table 1. BMI classification for children between 2-20 years (State of Alaska, 2012)

BMI for age percentiles	Weight classification
< 5 th	Underweight
5 th to < 85 th	Healthy weight
85 th to < 95 th	Overweight
≥ to 95 th	Obese

2 LITERATURE REVIEW

The Body Mass Index (BMI) equation was originally framed by Adolphe Quetelet, a Belgium mathematician and scientist, between 1830 and 1850 (Vinay, 2011; Chumlea, 2006). Adolphe was the first person to think of relating weight to height in a statistical manner. The BMI tool is fairly reliable; it is one of the tools used by physicians for evaluating patients' health status (Vinay, 2011). In 2006, Chumlea discussed many of the existing techniques for evaluating weight-related health problems and their limitations when applied to obese people. From his recommendations, among all the methods available to monitor obesity such as anthropometry, weight and stature, body mass index, abdominal circumference, skinfolds, bioelectric impedance analysis, body density, total body water, dual energy x-ray absorptiometry, BMI is currently the easiest and most informative index (Chumlea, 2006).

Over the years, there has been several ways of measuring weight while measurement of human height later received research focus so that BMI can be computed arithmetically. A technique of measuring human height using analogue type pyro electric sensors was carried out in Japan by Shinya et al., (2005). The sensors detect the feeble far-infrared rays emitted by the human body. They are installed in rest room ceilings and passageways to save energy. They arranged these sensors in the shape of a lattice on the ceiling and floors. Human heights were detected when the examinees pass through their bottom. The Conventional position and height detection techniques use image processing, RFID (Radio Frequency Identification) etc. They can acquire fixed accuracy, but it is difficult to use them in everyday life (Shinya et al., 2005).

Dipika et al. (2015) designed and constructed BMI machine using PIC 18F452. The weight sensing unit is made of load button cell which is efficient for weight measurement. The height sensing unit is made of Light

Dependent Resistor (LDR). The reduction in resistance value when dark light is casted on the LDR by human is used to determine the human height. It is quite obvious that resistance of the LDR may be interfered by the level of brightness or darkness of the environment where the BMI is being used.

3 MATERIALS AND METHOD

The functional parts that make up the designed BMI machine are presented in the form of block diagram in Figure 1. The human height measurement unit consists of ultrasonic sensor which uses the principle of sound waves reflection (echo) to deduce human height. The weighing unit is made up of load cell and an amplifying circuit. The last unit is the processing unit which consists of microcontroller and Liquid Crystal Display (LCD). The microcontroller can be regarded as the heart of the BMI Machine. It receives signals from the two former units, computes the value of height, weight, BMI and sends the results to LCD.

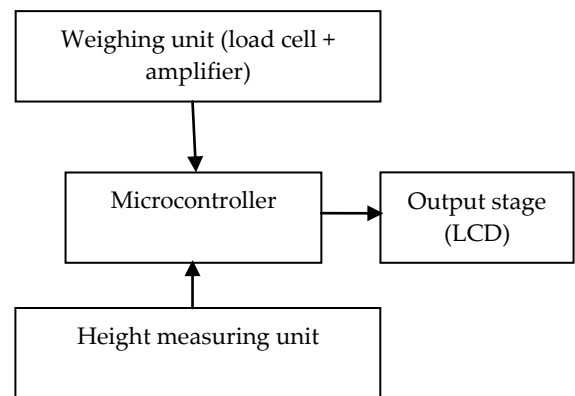


Fig. 1: Block diagram of the developed BMI Machine

3.1 LOAD CELL AMPLIFIER WITH 24 BITS ANALOG-TO-DIGITAL CONVERTER

Load cells are force sensors which convert weight into electrical voltage using the piezoelectric effect. There are different types of load cells with varying capacity rated in mass unit (kg or pound). The load cell type used for this project is a 200kg Load Button Cell shown in Figure 2. The load cell produces an output voltage proportional to the magnitude of the weight sensed by the strain gauges. When the load cell is at its maximum rated weight (i.e. 200kg), then the output voltage due to piezo effect via terminals +S and -S will be 20 mV per 1V applied to the load cell's excitation terminals +E and -E.

The excitation terminals were powered with 5V which implies that when a load of 200 kg is applied to the load cell, the output voltage will be (20 mV × 5) or 100 mV. This output is an analogue signal which cannot be fed directly into the microcontroller. To convert a continuously varying physical quantity into discrete electrical signals, an Analog-to-Digital Converter (ADC) is needed to translate the analog signals to digital numbers so that the signal can be recognized by microcontroller (Lawal, 2016). Based on Avia Semiconductor's patented technology, HX711 is a precision programmable gain amplifier (PGA) integrated with a 24-bit ADC designed for interfacing

directly with a bridge sensor for digital measurement of weight and industrial control applications (Avia datasheet, 2011).

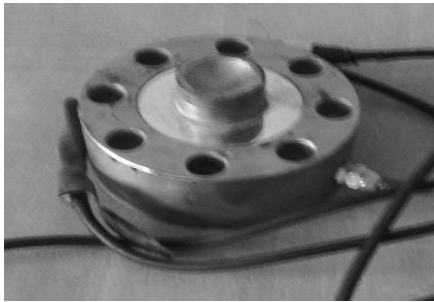


Fig. 2: Image of Load Cell Button

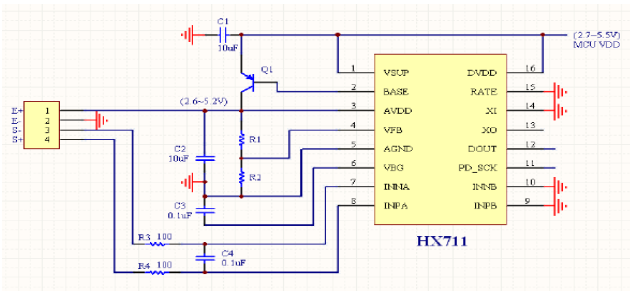


Fig. 3: Circuit Diagram of Strain gauge amplifier (Avia Semiconductor datasheet HX711, 2011; Sarah, 2003)

The input multiplexer selects either channel A (pin 7 INNA) or B (pin 8 INPA) differential input to the PGA. Channel A can be programmed with a gain of up to 128, corresponding to a full-scale differential input voltage of ± 20 mV, when +5 V is supplied to the AVDD pin of the PGA. Channel B has a fixed gain of 32. The on-chip power supply regulator in the PGA eliminates the need for an external supply regulator to provide power for the ADC and the load cell via Q1. The HX711 PGA also has on-chip oscillator which provides clock pulses needed for the ADC conversion. On-chip power on-reset circuitry simplifies digital interface initialization. There is no programming needed for the internal registers. All control instructions required by the HX711 are sent through the programmed arduino microcontroller. The load cell amplifier output (i.e. pin 3 and 4 as shown in figure 3) is linked to the microcontroller via of pin 12 (DOOUT) and pin 11 (PD_SCK) of the HX711 to pin 8 and pin 9 of the arduino microcontroller respectively.

3.2 THE ULTRASONIC SENSOR

Ultrasonic sensors produce sound waves at frequencies (above 20KHz) which are beyond human hearing capability. A complete ultrasonic transceiver consists of a transmitter and a receiver. The ultrasonic sensor used in this work operates in the pitch catch mode. The transmitter and the receiver are installed at the same side thus functioning as a single transceiver (Mohd, 2016). Ultrasonic transmitter emits an ultrasonic wave in one direction, and immediately starts a time counter. The wave spread in the air, and is reflected when encounters the obstacles along its path. The ultrasonic receiver stops the time count when it receives the reflected wave. Since wave velocity in the air is 340 m/s, and the wave’s time of flight is recorded as *t*, we can

calculate the distance *h* between the obstacle and the transmitter as $h = 340t / 2$. This is the echo method of probing depth otherwise known as time difference distance measurement principle. The Ultrasonic sensor used for this project is the Arduino ultrasonic range detector HC-SR04 shown in figure 4. It is capable of detecting obstacle within a range of 2cm to 500cm with a voltage supply of 5 V (EF03085 HC-SR04 User Guide and Arduino Ultrasonic Range Detection Sensor HC-SR04 Manual). The sensor sends out an ultrasound of about 40 KHz when it is triggered through pin 2. As soon as the wave hits an obstacle, it is reflected and returned to the receiver so that a pulse (5 V) is produced by pin 3 (echo). The Arduino microcontroller measures and records the time *t* taken by the ultrasound wave to travel between the transmitter and receiver.

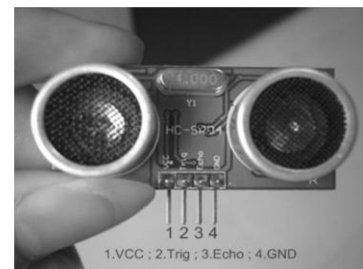


Fig. 4: Image of the HC-SR04 Ultrasonic Sensor (EF03085 HC-SR04 User Guide)

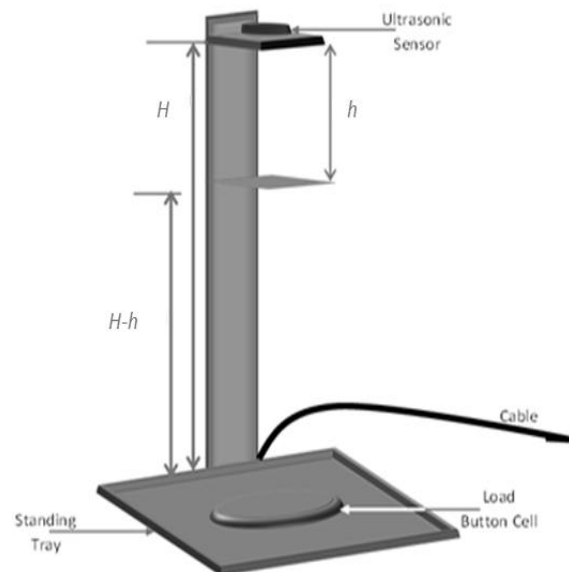


Fig. 5: Set up of BMI Machine

The measured time *t* is used to calculate the distance *h* between the sensor and the target (human head) by applying equation (1). The ultrasonic sensor is placed at a fixed known value *H* (see figure 5) from ground level (floor).

$$h = \frac{vt}{2} \tag{1}$$

Where *v* is the speed of sound in air (340ms⁻¹)

The human height is then computed as the difference between the calculated distance *h* and sensor height *H* from ground level i.e. *H-h*.

3.3 THE PROCESSING UNIT

This stage is made up of the Arduino Uno ATmega328p microcontroller (MCU) and a 20x4 JHD204A Liquid Crystal Display (LCD). A microcontroller is small size computer on a single IC containing processor core, memory and programmable input-output peripheral. Microcontrollers are used for embedded applications, in contrast with microprocessor which are used for personal computers and other general purpose applications. The Atmega328 is a low power, high performance; CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. The Atmega328 provides 32 Kilobytes of in-system self-programmable memory with read and write capability and 1Kilobyte of Electrically Erasable Programmable Read Only Memory (EPROM). Further details on Atmega32 can be found in Pratik et al., (2014). The MCU serves as the heart of the entire system as it coordinates all the activities of other sub-circuits. The microcontroller is interfaced with the ultrasonic sensor as shown below.

The LCD is an output device which displays the result of all the measurements i.e. the height, weight and BMI. A Digchip 20 character x 4 lines JHD204A liquid crystal display was used in the system developed. It is a-16 pin LCD which works with a maximum power supply of 5.0 V and the data can be sent either 4 bit (2 operations) or 8-bit (1 operation) so that it can be interfaced to an 8-bit Microcontroller. Here 4 bits (2 operation) system was used. Details of the pin configuration of this LCD can be found in JHD204A Datasheet. The C++ code that interfaced LCD to the arduino platform is also embedded in the microcontroller. The entire system is powered with 5 V supplied by a regulated DC power supply. A snap shot of the developed BMI Instrument showing its components is depicted in figure 6 while its front view is displayed in Figure 7.

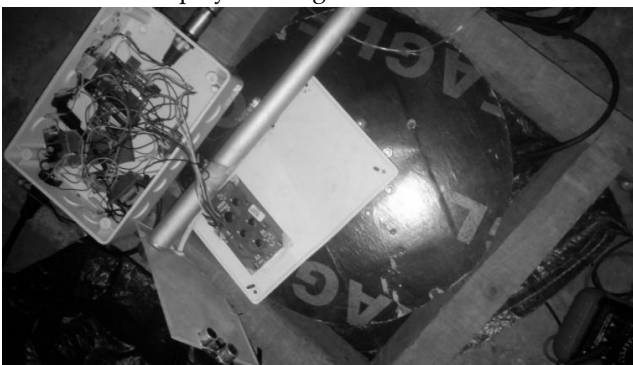


Fig. 6: The snap shot of the developed BMI machine showing the internal circuitry and the ultrasonic sensor

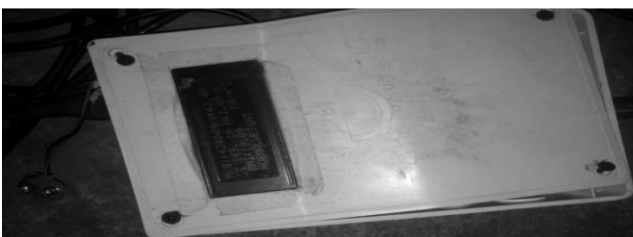


Fig. 7: The snap shot of the front view of the developed BMI measurement Instrument

3.4 PRINCIPLE OF OPERATION

When the BMI machine is powered on, in the absence of human standing on the weighing unit, the MCU initializes, then detects zero human height (because $H-h = 0$) and zero mass. As soon as a man whose BMI is to be measured stands in the L-shaped wooden stand shown in figure 5, the ultrasonic sensor generates a shorter pulse because the ultrasound now travels a shorter distance as it hits human head and is reflected to the receiver. The pulse is sent to the arduino microcontroller which converts the processed time t (period) into distance h using equation (1). The human height is determined by subtracting h from the sensor's height H . Also, the load cell amplifier senses an appreciable output voltage which is sent to the MCU via the HX711 PGA. The signal received from the PGA is also used to compute human mass while equation (2) evaluates the BMI value. The C++ code embedded in the MCU is responsible for all the numerical computations and operations of the system.

$$BMI = \frac{\text{weight of the body}}{(\text{height of body})^2} \quad (2)$$

4 RESULTS AND DISCUSSION

The developed machine was tested and calibrated by comparing its results with expected nominal values in the Department of Physics Laboratory, FUTA (Federal University of Technology, Akure, Ondo state, Nigeria). Standard masses were placed on the stand; the results displayed on the LCD screen were recorded and plotted against the equivalent standard values. A correlation factor and standard deviation of 0.99 and 10.5 g were obtained with a P-value of 0.93 which implies a significant level greater than 0.05%. These showed that there is a strong correlation between standard mass values and the measured values. Table 2 shows the results of the repeatability of the weighing machine. A 50 kg body was placed on the weighing machine and the displayed results were recorded after every 10 s.

Table 3 presents several human heights measured manually using a tape rule and the equivalent values obtained by the ultrasonic measurement. Similarly, the results were analysed yielding a correlation factor of 0.97 and average error of ± 0.0064 cm.

Table 2. Repeatability of the Weighing Machine

Time (s)	Mass Reading (kg)
0	50.0145
10	50.1023
20	49.983
30	50.0125
40	50.1102
60	49.9450
70	50.0023
80	50.0125
90	50.0023
100	50.0134

Table 3. Comparison of Human heights measured by the Ultrasonic sensor and Tape rule

Tape Rule (m)	Ultrasonic (m)	Error (m)
1.54	1.553	0.013
1.52	1.534	0.014
1.5	1.491	-0.009
1.49	1.484	-0.006
1.46	1.473	0.013
1.45	1.455	0.005
1.42	1.432	0.012
1.41	1.414	0.004
1.38	1.392	0.012

5 CONCLUSION

A locally made BMI machine was designed and constructed. The machine was tested and the results obtained practically match that of ready-made scales with minimal errors. The correlation values of the height and weight measured for various people when compared with the commercially available measurement scales were 0.97 and 0.99 respectively. The BMI machine can be used to determine the changes in human health status. It is an important indicator of nutritional status; being underweight, normal, overweight, obese or highly obese which adversely influence mortality and morbidity rate.

The cost of constructing this BMI machine was about ₦50,000 (140 USD) whereas a typical BMI Machine cost about 800 USD in the market. The local built BMI machine holds several advantages over the commercially available ones which are highly customized. These include local serviceability, affordability and simplicity. It is also designed to withstand the weather conditions of the tropical climate therefore, does not require special room conditioning for proper operation. The performance of the constructed instrument can be improved by enclosing the entire instrument in a customized closed chamber so as to shield the ultrasonic sensor from external interference.

ACKNOWLEDGEMENTS

The Authors wish to appreciate everyone who has contributed towards the success of this publication. However, it must be emphasized that this work receives no funding from any external source. The work was solely financed by the Authors.

REFERENCES

Arduino Ultrasonic Range Detection Sensor HC-SR04. Retrieved June 21, 2018, from <https://optimusdigital.ro/>

Avia Semiconductor Datasheet for HX711 Amplifier (2011). Retrieved December 21, 2014, from <http://www.aviaic.com/>

Carlene, P., Ned, R., Craig, A., Janet, B., Thomas, C., Maureen, F., Mary, A. G., Robert, L., & Carol, S., (2014). BMI Screening Guidelines for Schools. *Department of Public Health, State Library of Massachusetts*, Retrieved on March 5, 2018, from <http://www.mass.gov/eohhs/docs/dph/com-health/school/bmi-screening-guidelines-for-schools.pdf>

Centers for Diseases Control and Prevention (CDC) (2014): *Healthy Weight: About Child and Teen BMI* Retrieved June 25, 2018, from

www.cdc.gov/healthyweight/assessing/bmi/childrens_bmi/about_childrens_bmi.html

Chumlea, W. C. (2006). *Body Composition Assessment of Obesity. Overweight and the Metabolic Syndrome*. ISBN: 978-0-387-32163-9 Springer International, XII, 336. pp. 80

Dipika, S., Varsha R., Mhatre., Prashant, M. M., & Ayane, S. S. (2015). Measurement of Body Mass Index (BMI) using PIC 18F452 Microcontroller. *International Journal on Recent and Innovation Trends in Computing and Communication*, 3(4), 2213 – 2216. ISSN: 2321-8169.

EF03085 HC-SR04 User Guide on use of Ultrasonic Sensors. Retrieved June 21, 2018, from https://elec Freaks.com/estore/download/EF03085-HC-SR04_Ultrasonic_Module_User_Guide.pdf

Garrow, J.S., and Webster, J. (1985). Quetelet’s index (W/H²) as a measure of fatness. *International Journal of Obesity*, 9(2), 147-153.

Laura, J. M. (2017). Health Risk of Obesity, *Medline Plus, U.S. National Library of Medicine*. Retrieved June 23, 2018, from <https://medlineplus.gov/ency/patientinstructions/000348.htm>

Lawal, Y. B., Dada, J. B. and Ahmed-Ade, F. (2016). Construction of Automatic Temperature Controller for Monitoring Heating and Cooling systems. *Journal of Sustainable Technology*, 7(1), 1-5.

Mei, B.Z., Grummer-Strawn, L.M., Pietrobelli, A., Goulding, A., Goran, M.I. and Dietz, W. H., (2002). Validity of Body Mass Index compared with other body-composition screening indexes for the assessment of body fatness. *American journal of Clinical Nutrition*, 75(6), 978–85.

Michael, Lokuruka. (2013): Role of Obesity in Adult Health with Reference to Africa. *African Journal of Food Agriculture Nutrition and Development*, 13(1), 7089-7104.

Mohd Taufiq, Mohd Khairi, Sallehuddin Ibrahim, Mohd Amri Md Yunus and Mahdi Faramarzi. (2016). Contact and Non-contact Ultrasonic Measurement in the Food Industry: a review. *Measurement Science and Technology*, 27(1), 23. doi:10.1088/0957-0233/27/1/012001

Nihiser, A. J., Lee, S. M., Wechsler, H., Mckenna, M., Odom, E., Reinhold, C., Thompson, D. and Grummer-Strawn, L., (2007). Body Mass Index measurement in schools. *Journal of School Health*, 77(10), 651-671.

Non Communicable Diseases. *World Health Organization (WHO)*. Retrieved September 25, 2015, from <http://www.who.int/mediacentre/factsheets/fs355/en/>

Nuttall, F. Q., (2015). Body Mass Index: Obesity, BMI, and Health a critical review. *Nutrition Today*, 50(3), 117 – 128.

Pratik, P., Rahul, N., & Anup Singh, P. (2014). Design of Solar Insolation Level Detector and Data Logger, *International Journal of Current Engineering and Technology*, 4(3), 2083-2087.

Sarah, A. (2003): *Getting Started with Load Cells*. Retrieved March 8, 2018, from <https://learn.sparkfun.com/tutorials/getting-started-with-load-cells>

Shinya, O., Shigeo, K., & Hirohide, H. (2005). Human Position/Height Detection Using Analog Type Pyroelectric Sensors. *Proceeding of Embedded and Ubiquitous Computing – EUC 2005 Workshop*, (pp 306-315), December 6-9, 2005, Nagasaki, Japan.

State of Alaska (2009). Prevalence of Overweight and Obesity among Anchorage School District Students, 1998-2008. *Department of Health and Social Services, Division of Public Health, Section of Chronic Disease Prevention and Health Promotion*, 2(1).

State of Alaska (2012). Measuring Height/Weight and Calculating BMI Guidelines for Schools. *Department of Health and Social Services, Division of Public Health, Section of Women’s, Children’s and Family Health*.

Vinay, P. (2011). Introduction to Body Mass Index. Retrieved September 12, 2018, from <http://bmi4all.blogspot.com.ng/p/introduction.html>