ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 7, January 2020

Designing of an efficient electrical body fat analyzer

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Abstract: ***Bioelectrical body fat analyzer is employed to design a device to measure and calculating body fat percentage by using bioelectrical impedance analysis method. Bioelectrical impedance analysis is a method consisting of the passage of a painless electric current of low amplitude and low and high frequencies through the organism, applied by means of cables connected to electrodes or to conductive surfaces, which are placed in contact with the skin, permitting the measurement of resistance from the resistance body fat percentage can be obtain by substitute the resistance with height, weight, age, gender that the user enter it in the equations to get body fat percentage.***

I. INTRODUCTION

Determining your percent body fat is very important because the amount of fat in your body is related to health as well as fitness and sports performance it can influence the person to lose weight or mussel gain.

Fat is one of the basic components that make up the structure of your body. The other components include muscle, water, bone and your organs the brain, liver, kidneys, spleen, stomach, pancreas and intestines etc. All are necessary for normal, healthy functioning. There are many methods to measure body fat one of the method is bioelectrical impedance analysis.

Bioelectrical impedance analysis (BIA) is a method used for estimating body composition and in particular body fat. Since the advent of the first commercially available devices in the mid-1980s the method has become popular owing to its ease of use, portability of the equipment and it's relatively low cost compared to some of the other methods of body composition analysis. It is familiar in the consumer market as a simple instrument for estimating body fat. BIA actually determines the electrical impedance, or opposition to the flow of an electric current through body tissues which can then be used to calculate an estimate of total body water (TBW). TBW can be used to estimate fat-free body mass and by difference with body weight, body fat.

Electrical properties of tissues have been described since 1872. These properties were further described for a wider range of frequencies on larger range of tissues, including those that were damaged or undergoing change after death. Thomas set conducted the original studies using electrical impedance measurements as an index of total body water (TBW), using two subcutaneously inserted needles.

Manuscript received: 30 December 2019
Manuscript received in revised form: 26 January 2020
Manuscript accepted: 11 February 2020
Manuscript Available online: 15 February 2020

Hoffer et al and Nyboer first introduced the four-surface electrode BIA technique. A disadvantage of surface electrodes is that a high current (800μA) and high voltage must be utilized to decrease the instability of injected current related to cutaneous impedance (10 000Ω/cm^2). By the 1970s the foundations of BIA were established, including those that underpinned the relationships between the impedance and the body water content of the body. A variety of single frequency BIA analyzers then became commercially available and by the 1990s, the market included several multi-frequency analyzers. The use of BIA as a bedside method has increased because the equipment is portable and safe, the procedure is simple and noninvasive and the results are reproducible and rapidly obtained. More recently, segmental BIA has been developed to overcome inconsistencies between resistance ® and body mass of the trunk. Many of the early research studies showed that BIA was quite variable and it was not regarded by many as providing an accurate measure of body composition. In recent years technological improvements have made BIA a more reliable and therefore more acceptable way of measuring body composition. Nevertheless it is not a gold standard or reference method. Like all assessment tools, the result is only as good as the test done.

Although the instruments are straightforward to use, careful attention to the method of use (as described by the manufacturer) should be given. Simple devices to estimate body fat, often using BIA are available to consumers as body fat meters. These instruments are generally regarded as being less accurate than those used clinically or in nutritional and medical practice. They tend to under-read body fat percentage.

The impedance of cellular tissue can be modeled as a resistor (representing the extracellular path) in parallel with a resistor and capacitor in series (representing the intracellular path). This results in a change in impedance versus the frequency used in the measurement. The impedance measurement is generally measured from the wrist to the contralateral ankle and uses either two or four electrodes. A small current on the order of 1-10μA is passed between two electrodes and the voltage is measured between the same (for a two electrode configuration) or between the other two electrodes.

II. PROBLEM STATEMENT

Presently, there are numerous ways to measure body facts. These techniques such as dual energy X-ray and

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ISO 9001:2008 Certified
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Absorptiometry and computerized tomography are expensive, invasive and require exposure to dangerous radiation. Other techniques such as plethysmography and hydodensitometry are quite tedious. Using bioelectrical impedance analysis to develop a light hand-held portable device that could instantly estimate the body fat percentage of a person using electrical impedance signals from a skin fold of an arm, display the body fat percentage on an LCD.

III. OBJECTIVES

For this project, certain objectives must be met as a guideline through the process of the completion of it. These objectives are as follows:

- To design and develop a hand-held portable device that could estimate the body fat percentage of a person using electrical impedance signals and displays the body fat percentage on an LCD.
- To build a regression function that could map electrical impedance signals to body fat percentage.
- To evaluate the performance of the device in real time with real human subjects.

IV. SCOPE

Bioelectrical body fat analyzer project will focus on determination of body fat percentage using bioelectrical impedance analysis technic by measuring the voltage that comes from the electrode by the movement of the low current throw the electrode to generate the voltage. From this voltage the body fat percentage can be obtained by substitute it into the equations with height, weight, age, gender by the user.

V. LITERATURE REVIEW

This Section deals with literature review that consists of several parts such as body fat percentage measurement techniques and overview on non-invasive techniques. Moreover, it also covers a review of many previous researches on bioelectrical impedance analysis method, overview on BIA body fat percentage.

A. BODY FAT PERCENTAGE

Body fat percentage in simply way is the percentage of fat that your body contains, compared to everything else. Everything else includes your organs, muscles, bones, tendons, water and so on. These fats work to make your body to function properly it is essential that your body contains a certain amount of fat. Body fate helps regulate your body temperature, it cushions and insulate organs and is the main form of the body's energy storage. It is important for everyone to have a healthy amount of body fat. Having high amount of body fat will lead to incidence of diabetes; high blood pressure and other hear risks.

Both men and women carry different amounts of body fat percentage. The percentage of essential body fat for women is greater than that for men, due to the demands of childbearing and other hormonal functions. A super ripped male body builder who is minimizing body fat percentage could have a percentage down as low as 3-4%, while a super ripped female body builder who is minimizing body fat percentage would only get as low as 8-9%, A male athlete could be in fantastic shape and have 10% body fat, while a women at comparable level of athleticism and appearance might be at 18-24% body fat. To take the comparison to the other end of the spectrum, an overweight male at 25% will look vastly different than an overweight women at 32% as shown in table below.

Table 1: Healthy body fat percentage (ACE, 2009)

Description	Women	Men
Essential fat	10-13%	2-5%
Athletes	14-20%	6-13%
Fitness	21-24%	14-17%
Average	25-31%	18-24%
Obese	32%+	25%+

NON-INVASIVE BODY FAT PERCENTAGE ESTIMATION METHODS

There are five methods that can measure body fat percentage that might be varied from one to another in accuracy and other things.

SKIN FOLD CALIPER METHOD

The skin fold method measures your body fat percentage by pinching your fat with your fingers then measuring the thickness with a body fat caliper. The reading is given in millimeters, which you compare to a chart with age and gender to arrive at your body fat percentage. There are many different types of caliper tests, which range from only one site like with the Accurate measure Body Fat Caliper to a 7 site Jackson Pollack Method (some are as high as 12 sites). (rian Bambl B.S., 2011).

Anthropometric Method

This method uses body circumference measurements to estimate body fat percentages. The U.S. Navy method takes waist, neck and height circumference for men and hips, neck and height for women.(rian Bambl B.S., 2011).

HYDROSTATIC WEIGHING METHOD

This method is considered the "Gold Standard" (+/- 1.5% error) of body fat measurement that requires being submerged in a specialized tank of water. Because bone and muscle are denser than water, a person with a larger percentage of fat free mass will weight more in the water and have a lower percent body fat. Conversely, a large amount of fat mass will make the body lighter in water and have a higher percent body fat. Accuracy of the reading is contingent upon blowing all the air out of the lungs during pretest screening. The test takes about 20-30 minutes, costs around 100-150 and is available at research labs, universities or hospitals (rian Bambl B.S., 2011).

Dual Energy X-ray Absorptiometry (DEXA) Method

Dual Energy X-ray Absorptiometry known as DEXA is fast becoming the "new" gold standard of body fat measurement because it's based on a three-compartment

ISSN: 2277-3754
ISO 9001:2008 Certified
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model that divides the body into total body mineral, fat-free soft (lean) mass and fat tissue mass. Hydrostatic Weighing on the other hand only uses a 2 compartment model (fat free mass and fat mass).

DEXA also allows for body fat distribution analysis, so you can figure out with precision how fat is distributed in various parts of your body. In the past, DEXA was only used to measure bone mineral density for osteopenia and osteoporosis in older individuals. The procedure uses a body scanner with low dose x-rays, so it's completely safe and takes about 10-20 minutes. (Am J Clin Nutr 2005).

Bioelectric Impedance Analysis

Bioelectric Impedance Analysis or BIA determines the electrical impedance or opposition to the flow of an electric current through the body. Muscle has high water content and is highly conductive, while fat has lower water content and is not highly conductive. Based on the strength of the impedance along with height and weight metrics, the BIA scale will estimate fat-free body mass and body fat percentage.

Many consumer weight scales like omran Body Fat Monitor Scale also come with BIA capabilities and there are others that require holding the BIA device in your hands. Because the BIA test is based on body water balance, your state of hydration can impact the level of accuracy. (Am J Clin Nutr 2005).

Table 2: Comparison of the five methods

Method	Advantage	Disadvantage
Skin Fold Caliper	Accurate Dependable (when skilled at measuring) Repeatable	Variability of measurement (same exact spot needs to use each time) More than one-site test requires a skilled fitness professional (I've done these thousands of times) For people 35+ pounds overw
Anthropometric	Easy to Administer cheap	Questionable Accuracy
Hydrostatic Weighing	Very accurate, considered Gold Standard	Impractical Expensive Not repeatable (unless you liked repeatedly getting dunked in a tank and spending 150)
DEXA Scan	Very accurate	Expensive: Around 250 Not repeatable (unless you don't mind spending 250 every couple weeks)
Bioelectric Impedance Analysis	Very easy to administer	Questionable Accuracy
	Inexpensive (most weight scales around 50 or even less have BIA)	Variability of results dependent on hydration level

B. Further Investigation on Bioelectrical analysis

Bio-electrical Impedance Analysis or Bioimpedance Analysis (BIA) is a method of assessing your body composition, the measurement of body fat in relation to lean body mass.

Conceptual Assumptions

BIA is a method consisting of the passage of a painless electric current of low amplitude and low and high frequencies through the organism, applied by means of cables connected to electrodes or to conductive surface, which are placed in contact with the skin, permitting the measurement of resistance (R) and reactance (Xc). The R and Xc values are then used to calculate impedance (Z) and the phase angle (), and total body water (TBW) is estimated in addition to the quantity of extracellular (ECW) and intracellular (ICW) water. Fat-free mass (FFM) can then be calculated, assuming that TBW is a constant part of FFM. On this basis, other body compartments such as fat mass (FM) and body cell mass (BCM) can also be measured (Lukashi HC, 1985).

BODY COMPARTMENTS

FFM, which consists of all that is not body fat and involves the following components: bone mineral content (≈7%), extracellular water (≈29%), intracellular water (≈44%), and visceral protein. Many BIA equations are available in the literature for the estimate of FFM, varying in terms of the parameters included in multiple regression equations and in their applicability to different individuals, as can be seen in Table 3.

The first BIA equations date back to before 1980 and only include height^2 resistance. Later equations started to include other variables such as weight, age, gender, reactance and anthropometric measurements of trunk and/or extremities in order to improve the accuracy of prediction. Thus, FFM can be determined with a single frequency BIA instrument as long as hydration is normal and the BIA equations are applicable to the study population, taking into consideration gender, age and ethnicity (Kyle U, 2004).

TOTAL BODY WATER (TBW)

Another very important body compartment is total body water (TBW) and its divisions into extracellular water (ECW) and intracellular water (ICW). A single frequency in BIA usually implies a measurement of impedance of 50 kHz and this type of impedance is limited in distinguishing the distribution of body water in the intra and extracellular compartments. The ability of multifrequency impedance in differentiating between total body water and ICW and ECW is potentially important for the description of the dislocation of fluid balance and for the exploration of possible variations in

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ISO 9001:2008 Certified
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hydration levels in some special clinical situations, such as renal diseases (Zhu F, 2008, Park J, 2009). Thus, equations elaborated for populations in normal states of hydration usually are not valid for individuals with altered hydration since states of hypo and hyper hydration affect the electrolyte balance, which in turn will influence the BIA measurements regardless of the changes in fluids. Furthermore, in a retrospective study of patients on hemodialysis, Fiedler et al. (2009) verified that the BIA is so good mortality predictor as serum proteins. The authors also suggested monitoring the vectorial graph phase angle, to follow differences in the evolution of nutritional status and hydration levels (Nephrol Dial Transplant, 2009).

Extracellular Water (ECW) And Intracellular water (ICW)

The ECW: ICW ratio is a factor known to limit the applicability of predictive equations generated by BIA for external populations. BIA does not permit a precise assessment of TBW and ECW when body water compartments are submitted to acute changes (De Lorenzo A, 1994) and the mean body hydration of FFM can also vary with age (90% for newborn infants, about 75% for 10-year-old children and 73% for healthy adults). Beyond these other clinical situations deserve attention to influence the ratio between ECW and ICW, as hemodynamic changes (including hypovolemic shock, cardiac failure), variations in body temperature (fever, postoperative hypothermia) and gastric stasis (Kushner R, 1996).

According to Ellis et al (Ellis KJ, 1999), single frequency BIA models (50 kHz) mainly reflect the ECW space, which represents a constant proportion of TBW under normal conditions. An increase in ECW or in the ECW/TBW ratio may indicate edema and /or malnutrition. In contrast, multiple frequencies BIA seems to be sensitive to these changes even when no significant change occurs in body weight.

Still regarding the body compartments and now considering FFM to be all that is not body fat, it can be seen that BCM is the protein-rich compartment that is affected in catabolic states and the loss of BCM is associated with unsatisfactory clinical results. In hyper hydrated patients, a precise determination of FFM may fail to detect protein malnutrition due to the expansion of ECW. Estimating the size is difficult since this is a complex compartment consisting of all non-adipose cells and of the aqueous compartment of the adipocytes.

FM

FM, consisting of total body fat and obtained by subtracting FFM from total body weight.

C. Types of Bioelectrical Impedance

Single –frequency BIA (SF-BIA)

Single –frequency BIA, (SF-BIA) as previously mentioned. In this method, a 50 kHz current is passed between surface electrodes placed on the hand and foot. Some BIA instruments use other sites such as foot-foot and hand-to-hand electrodes. In this case, the subject is positioned vertically and the conducting surfaces enter in contact with one of the body extremities, foot-foot or hand –to-hand. The vertical model is easy to apply since it only requires the subject to stand up barefoot on the platform that contains the electrodes (foot-foot), or to hold a hand –to-hand device (Mialich MS, 2011). The foot-foot system is usually employed for domestic use, i.e., it is a portable scale of easy use (Kyle U, 2004). This type of BIA is of low cost, is commercially available in several stores, is portable and easy to handle; however, in most cases it does not provide crude resistance and reactance values. However, the foot-foot system is also available in some professional models.

Another model of BIA equipment uses four electrodes, two of which are fixed to the dorsal region of the hand and two to the dorsal region of the foot of the subject on the same side of his body. An electrical current is then applied to the source (distal) electrodes and the fall in tension due to impedance is detected by the proximal electrodes. For this type of analysis, the subject must be in the horizontal position (Kyle U, 2004).

These 50 Hz BIA instruments do not strictly measure TBW, but rather weighted sum of the resistivity (≈25%) of ECW and ICW. In this way, SF-BIA permits an estimate of FFM and TBW but differences in ICW cannot be determined. Although SF-BIA is not valid under conditions of significantly altered hydration, it can be used to estimate absolute FFM or TBM or TBW in normally hydrated individuals.

Multifrequency BIA (MF-BIA)

Multifrequency BIA (MF-BIA) uses different frequencies (0,1,5,50,100,100,200 and 500kHz) to estimate FFM, TBW, ICW and ECW. Poor reproducibility has been observed at frequencies below 5 kHz and above 200 kHz, especially for reactance at low frequencies (Hannan wj, 1994).

In general, multifrequency impedance does not improve the estimate of body composition compared to single-frequency impedance, but can provide an accurate and precise estimate of TBW and ECW, which is limited when a single-frequency (50HZ) instrument is used. Some relevant aspects to be considered during the application of this method are: safety, standardization of the measurements, bioelectrical parameters, validity, clinical use and limitations.

Electrode

Electrode Shape

In bioelectrical impedance analysis, the geometrical structure of electrode has a strong impact on elementary data retrieved during the measurement process. In bioelectrical impedance analysis electrodes are defined as isoelectric materials with a negligible voltage drop along the connectors. The minimum numbers of electrodes required to perform the bioelectrical impedance measurements are two, one for current injection with the assumption of zero potential difference and the other for collecting the voltage drop with a negligible current flow

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ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
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and is more affected by position. (Martinsen, O.G, 2011) and the usage of more than two potential collecting electrodes or octapolar electrode method were used for segmental bioelectrical impedance studies to assess compartments in different body segments (Marini, E, 2013).

Ag-AgCI electrodes are now used in most bioelectrical impedance measurements because it has a well-defined DC potential with electrolyte gel to minimize the gap impedance between skin and electrodes. Circular and rectangular electrode shapes with a contact area greater than 4 cm^2 are the most commonly used shapes (Kyle, U.G, 2004).

Two-Electrode and Four –Electrode Methods

The bioelectrical impedance measurement process is conducted by either the two electrodes or four-electrode methods. In both the methods, the surface electrodes through which the current signal is injected are known as the current electrode so the driving electrodes and the electrodes on which the frequency dependent ac potential (f) is measured are called voltage electrodes or sensing electrodes (as shown by blue colored electrodes. As the name tells, the two-electrode method uses only two electrodes for impedance measurement, and hence the current signal injection and voltage measurement are conducted with same electrodes. The two-electrode method, therefore, suffers from the contact impedance problem and the measurement data contains the voltage drop due to the contact impedance. In the four-electrode method, two separate electrode pairs are used for current injection and voltage measurements and hence the four-electrode method is found as an impedance measurement method with a linear array of four electrodes attached to the SUT. The four electrode method injects a constant amplitude current signal to the SUT through the outer electrodes called current electrodes or the driving electrodes and the frequency dependent developed voltage signals are measured across two points within the current electrode through the inner electrodes called voltage electrodes.

Measurement Error

Errors in bioelectrical impedance measurements are caused by many factors such as motion, miss-positioning, connector length and fabrication errors. Moreover, the diversity of the commercially available bioelectrical impedance analyzers causes a wide range of fluctuations in measurements between the devices. Thus the calibration of the components inside a bioelectrical impedance analyzer such as signal generator, sensing apparatus, scales of weight and height and electrical interference should be conducted to ensure the reliability of the bioelectrical impedance analyzers. (Kyle, U.G, 2004).

Bioelectrical impedance analysis devices

There are many companies that produce devices related to bioelectrical impedance analysis to measure body fat.

VI. METHODOLOGY

This section includes the necessary procedures for the development of this project besides hardware and software description of the system and finally with the calculation for equations of body fat percentage.

Hardware

Electrical Design

The electrode will be attach to 4 points on the body two on the wrist and two on the ipsilateral ankle then a 500µA current will flow between the electrodes. Since the whole-body can be modeled as a linear circuit. The ratio between amplitudes of voltage and current oscillations is the impedance module, the phase difference between measured voltage and stimulation current is the impedance phase.

Microcontroller Arduino UNO

Arduino UNO is a single-board microcontroller based on the A Tmega328 which able to sense the surrounding by receiving input from a various type of sensors and able to affect its environments by controlling lights, motors and other actuators. Arduino UNO board consists of thirteen digital input/output pins, six analog inputs, a sixteen MHz ceramic resonator a USB connection to connect the board to computer, a power jack to supply the board with an AC-to-DC adapter or battery an ICSP header and a reset button. This open-source hardware board is design around an 8-bit Atmel AVR microcontroller, or a 32-bit Atmel ARM and it is programmed using C language or C++ language. In this project the microcontroller will send the voltage that come from the body throw the electrode to the pc (MATLAB) to substitute it to the equation of the body fat percentage and send the value to Arduino to display it using LCD that is connected to the Arduino.

Software Design

MATLAB is a programming environment for algorithm development, data analysis, visualization and numerical computation. This software is developed by Math Works and he programming code is written in C, C++ and Java language. Besides, MATLAB can be used in a wide range of application in academic, research institutions and industry. It consists of signal and image, processing, communications, control design, test and measurement, financial modeling and analysis and computation biology. For this project, MATLAB application is used for the user to insert age, weight, height and gender then substitute the voltage of the body that comes from Arduino then resend the value of body fat percentage to Arduino to display it using LCD.

Regression Equations

These equations are used to measure body fat percentage by inserting the age, weight, Height, gender. For the male the gender will be I and the female will be 0.

1. TBW = 0.372* (Height 2/Resistance)+(3.05*gender)+(0.142*Weight)-(0.069*Age)
2. FFM= TBW/0.73
3. FM= Weight-FFM

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 9, Issue 7, January 2020

4. Body fat = (FM/Weight)* 100
5. BMI= (Weight/Height 2)*100003.

VII. CONCLUSION AND RECOMMENDATIONS

Conclusion

To conclude; in this project the part of design have been achieved. By designing an electrical body fat analyzer device that is cheap and a useful to use by any one by using bioelectrical impedance analysis. Bioelectrical impedance analysis is a method to measure a body fat by sending electrical current through the body and getting the output signal then by applying the equations we can get the body fat percentage.

Recommendations

As with most projects undertaken there is always room for improvement. The first improvement that can be sent the signal to smart phone for data logging. The other improvement is to have connection between the Arduino and PC (MATLAB) wirelessly.

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