PORTABLE ELECTRIC MUSCLE STIMULATION DEVICE

A GRADUATION PROJECT TO THE BIOMEDICAL ENGINEERING DEPARTMENT OF NEAR EAST UNIVERSITY

by

FAISAL ALREFAIY

AHMAD ASIL

HANI ALOKLA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR DEGREE IN

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DECLARATION

We hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Faisal Alrefaiy

Signature:

Ahmad Asil

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Hani Alokla

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Date:

ACKNOWLEDGMENT

To our supervisor, Mr. Faith Nurcin, you inspired us to do this project, we appreciate your supervision, your patience, your commitment. We aimed for the stars at the beginning, its true that we landed at the moon but you know something about us, we are hard workers and we will reach the stars one day.

We would like to thank Asst. Prof. Terin Adali, you will be always our guidance in hard work, and commitment. you always encouraged us to be the best version of our selves and to keep asking and wondering.

To our parents, our families, without you, there is no us. We will keep your heads up, always.

To my childhood, I am still loyal.

ABSTRACT

Treatment via electricity has been discovered thousand years ago. The ancient Egyptians, the Greeks, and romans noticed that electrical fishes can generate electric shocks to treat pain. In the last two centuries, natural electric generators have been replaced by manmade devices. This happened through multi phases process. At the beginning, they used static electric currents (Franklinism), where friction generator was used. After that, the method of applying direct and pulsed electrical current to the skin by chemicals was called (Galvanism). At last, the electrical current was applied irregularly in alternate directions and it was called (Faradism). Finally, they used high frequency currents mechanism and it was called (d'Arsonvalisation). In the twentieth century, electric therapy was canned due to the lack of scientific bases. During the second half of the 20^{th} century, electrotherapy experienced a restoration. The experiments on animals allowed us to understand its neurophysiological affects in more details. Electrical muscle stimulation can be used to increase muscle strength, smooth voluntary motor function, in the retardation and reeducation of the muscles, and in increasing blood circulation. In this project, we aim to develop a portable EMS device, which can produce a variety of different currents with different periods of time. A future aspect will be discussed to add an active biofeedback for skin impedance measurement to enhance the ability of the EMS to affect the muscle.

Keywords: muscles, stimulation, Russian current, electrotherapy, muscle, Arduino, muscle spasm, muscle retardation.

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CHAPTER ONE

INTRODUCTION

We can consider the cell as a capacitor. The cell membrane is the dielectric, the ionic solutions on the both sides of the membrane represent the plates, and the difference in concentrations of the ions among each side can generate an action potential with value of -70 to -90 mV (referenced with the extracellular fluid). Action potential can be generated by the discharge of ions through the membrane. This is caused by the opening and closing of the ion gates in the phospholipid membrane. This will lead to the generation of the action current. This action current can cause depolarization and repolarization to the adjacent cells membrane, passing electrical current through the targeted tissue is considered the method for mimicking this action current in order to affect the polarity of the cells membrane the most used method. (Prutchi & Norris, 2005)

1.1 The Nerve

The nerve is made of a group of fibers (fascicles). Axons must be electrically isolated from each other to preserve channel separation. Each axon, whether it is bare or it is with myelin, is covered by a membrane that we call neurilemma. Axons are grouped in a bundle (funiculus) and they are surrounded by a connective tissue that we call (perineurium). a bundle contains the fibers that are grouped with interstitial connective tissue (endoneurium). A group of bundles can form a nerve. The outer part of the nerve is made of a thin layer of connective tissue (epineurium). A nerve bundle contains both efferent fibers (motor fibers, signal direction toward periphery) and afferent fibers (receptor signals toward CNS). As each of these layers have different thicknesses and conductivity levels, they have an important role in determining current density fields and the exogenic excitation threshold.

1.2 Synapses

a synapse, is where the signal between two neurons take place. The signal may pass, blocked, or it can be even modified. There are two types of synapses: chemical and electrical synapse.

1.2.1 Chemical Synapses

Central nervous system synapses are mostly chemical. Neurotransmitters can directly activate the gated membrane channels. The neurotransmitter function is localized on receipting proteins called (ligands) on the surface of the neuron. The chemical synapse can only allow unidirectional pathway. The neuron that makes the neurotransmitter is called (presynaptic) and the signal receiving neuron is called (postsynaptic). Ligand activated channels are the chemically activated ion channels in the postsynaptic. Receptor properties determine the excitatory and inhibitory effects. Neurotransmitters are chemicals such as adrenalin. (Grimnes & Martinsen, 2015).

1.2.2 Electrical Synapses

In this type of synapses, the distance between the cell membranes is very short – Nano meters- compared with the chemical ones. The junction points between the membranes have small tubules openings between their intracellular sections that is called (gap junctions), there function is to allow direct ionic flow. Gap junctions are existing in the smooth muscles and in the cardiac muscle. Their function is to allow bidirectional signal transmission between adjacent muscle cells so that each cell does not need a direct innervation.

1.2.3 Target Tissue

This type we call it usually the other neurons. When an action potential reaches the axon, its divide to many synapses. Target tissue types include muscles, and internal organs.

1.3 Excitation

Neuron excitation depends on the total information collected from the presynaptic terminals. Due to the huge amount of inputs, single input has no influence. Inhibitory inputs have more influence because their number is less than the excitatory presynaptic terminals. In the nerve system, there is summation both spatial and temporal. The electric current density is dependent on the electrode surface area, when its increased, the current density threshold is lower because of the summation effect of the receptor responses in the skin. Because of the temporal summation, the excitatory signals must be coordinated in order to trigger the neuron. However, slow changes of the presynaptic DC levels may also make a cell more or less excitable. (Martinsenet, 2004).

CHAPTER TWO

ELECTRIC MUSCLE STIMULATION THERAPY TYPES

Clinical studies showed that an appropriate electrical stimulation can help a denervated muscle to contract, this contraction can help limit edema and venous stasis within a muscle, and it can delay muscle fiber degeneration. There was a study that showed electric muscle stimulation can also decrease healing time of the muscle. The applications of muscle stimulation devices are generally the following:

2.1 Muscle spasm relaxation.

Muscle spasm can cause localized pain in the muscle. Electric stimulation is used to force the muscle off the spastic. To do that, the electric stimulation will constantly flex the muscle to its fatigue point and then release off its spasm. Its like holding a weight with muscle until fatigue point is reached and then liberating the muscle from that weight, which will make the muscle get rid of the spasm.

2.2 Retardation of disuse atrophy.

Muscles dereliction leanness is the decrement of the muscle due to lack of proper movement of the muscle. We use electrical stimulation for the contraction of the muscles to assist restoring is strength and other movement abilities, cycled or alternating output signals are used in this kind of therapy in order to generate periodic contractions and rest periods.

2.3 Muscle re-education.

Electric stimulation in this type of therapy aims to assist patients with stroke or joint surgeries, where they find hardness in flexing their muscles. Applying the electric pulse while the patient is trying to contract his muscle is the main goal of this therapy so the brain can get used to send the signals for the effected part of the body by its own.

2.4 Blood circulation increment.

This type of therapy is used to increase blood circulation through the muscle by duplicating the regular muscle contractions the helps the stimulation of fluid and blood pumping within the venous and the lymphatic channels back to the heat.

CHAPTER THREE

MATERIALS AND METHOD

3.1 An overview of the circuit

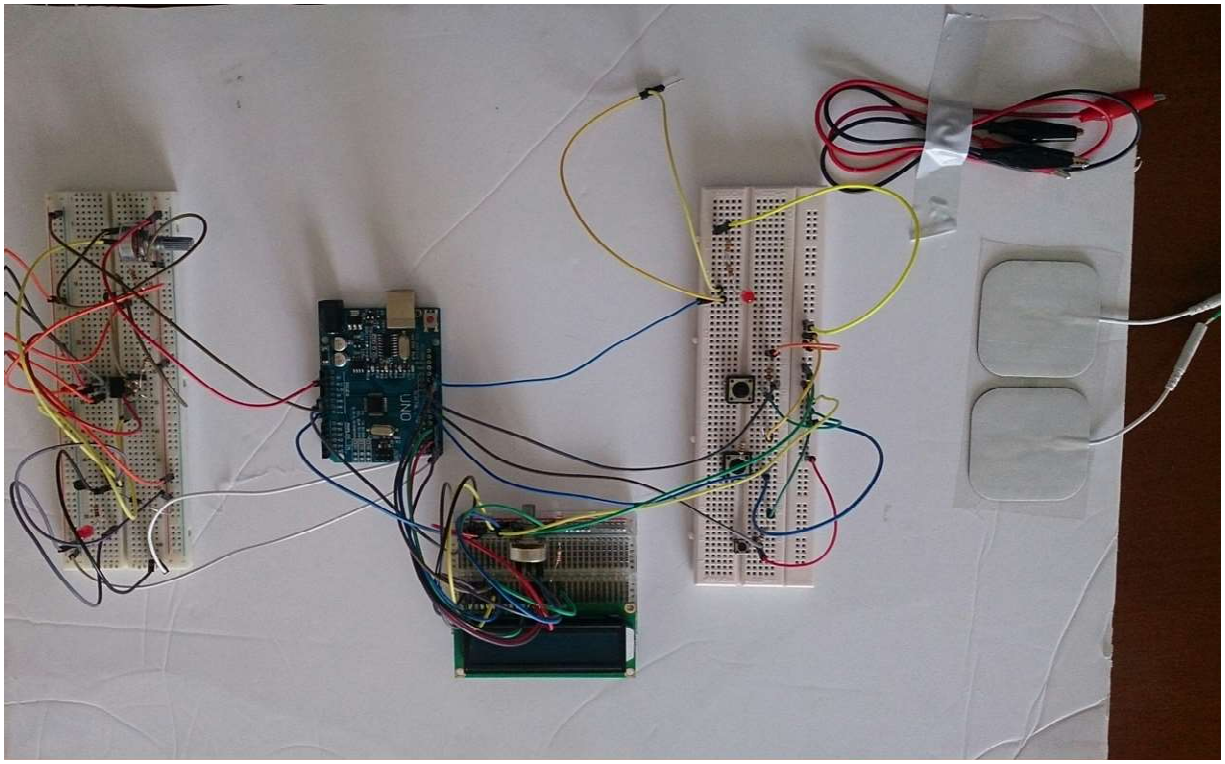

Figure 1: Overview of the device

The EMS device that we designed contains four Main Parts: Pulse signal generator circuit, Arduino UNO, LCD screen, Output signal circuit. We can use a 5V battery or a USB cable as a power source, and we have two electrodes and their cables ready to be connected to the patient.

We will discuss each part briefly in this chapter.

3.2 Pulse signal generator circuit

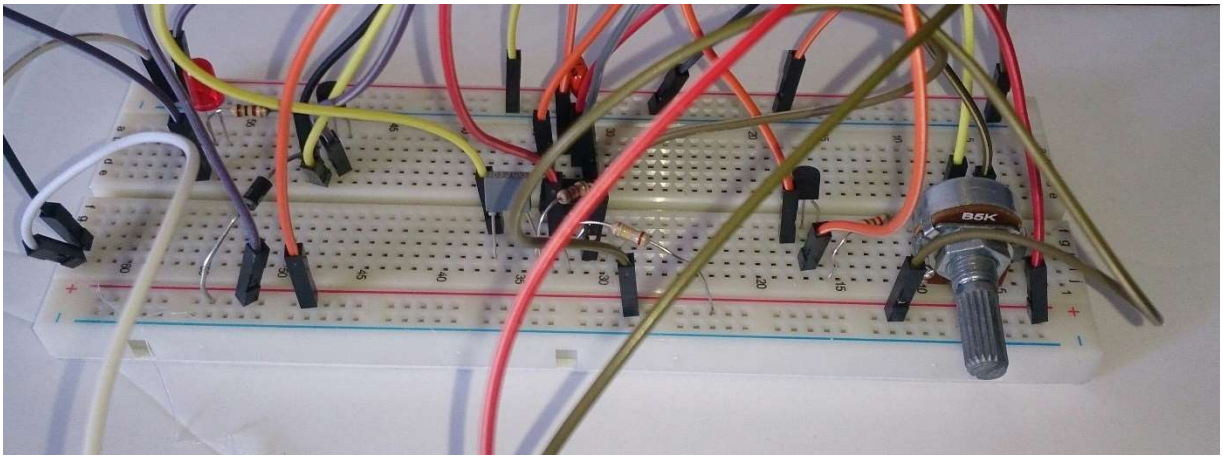

Figure 2: Pulse generator circuit

This circuit produces a constant pulse signal that goes through Arduino to the output circuit. We use IC 7555 microchip and two BC-327 transistors and four Resistors and a variable resistors and two capacitors. This circuit takes the 5V Input and Turns it into a pulse signal and then transfer it to the Arduino.

3.3 Arduino UNO

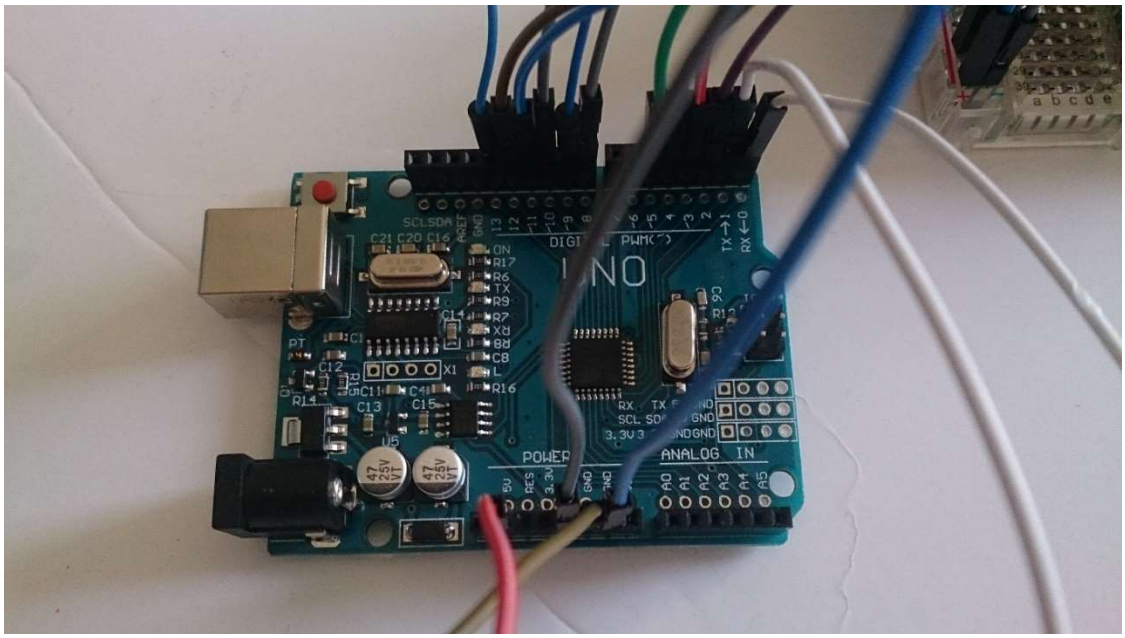

Figure 3: Arduino UNO

This is the mastermind of the device; it processes the signal coming from the Pulse signal generator circuit and then sends the wanted signal to the output signal circuit. It also sends the name of the signal and the timer to the LCD screen to show it. It can be powered by a normal 5v battery, or from any phone charger, or from any computer through the USB plug. The Arduino has an algorithm programed in it for the three signals that we want to generate: muscle spasm, muscle retardation, and Muscle re-education.

3.4 Output signal circuit

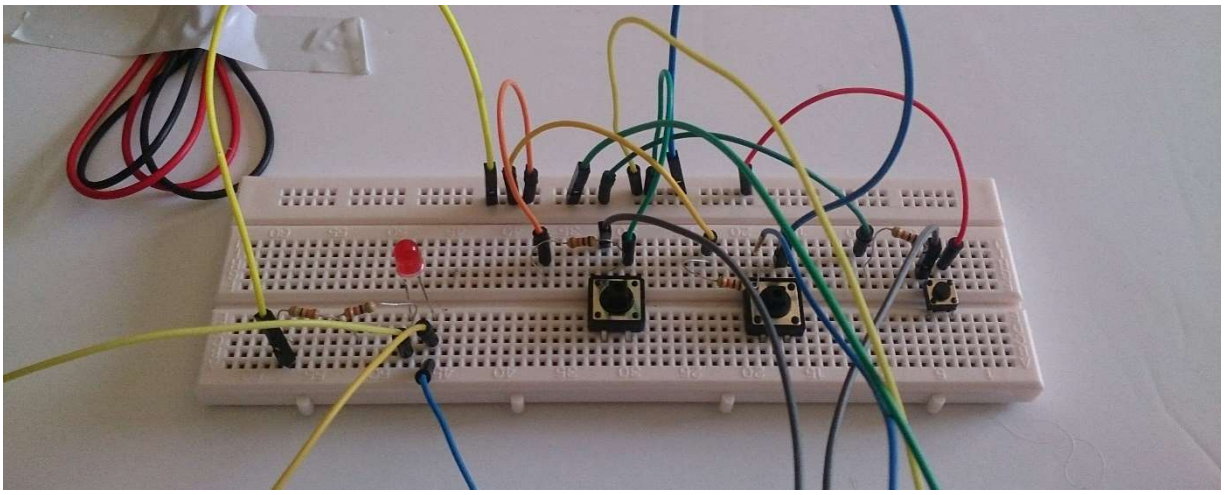

Figure 4: Output signal circuit

This circuit has two objectives, the first is to give an interface to the user to choose the signal that he needs to generate, and the other is to output it. This circuit is connected to the Arduino directly so that when a signal is chosen the Arduino sends it to the output of this circuit.

3.5 LED screen

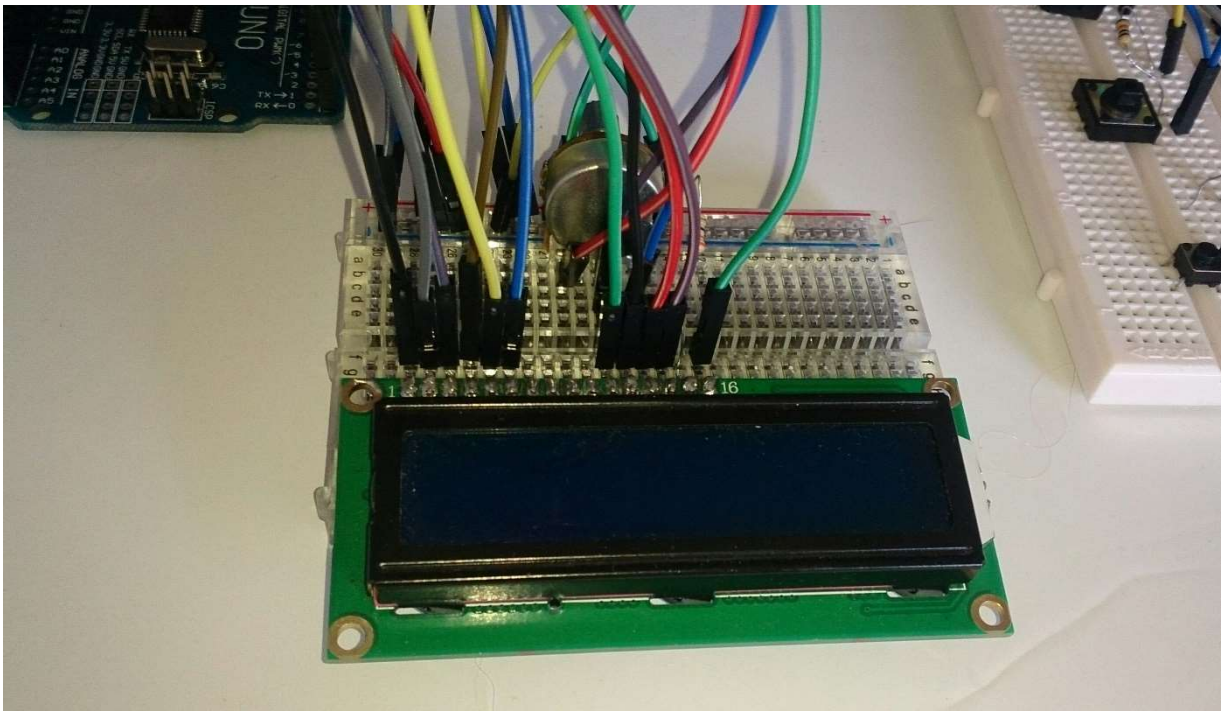

Figure 5: LED screen

This is the screen that outputs the signal that we are currently using and the duration of it.

3.6 Electrodes placement

- around the affected area.
- parallel to the affected area.
- Near the harmed spinal cord area.
- Sensitive trigger points where the nerve can be stimulated.
- Where the affected area is deep inside the anatomy of the body, like deep shoulder pain, then the electrodes must be localized far from each other's to increase the intensity

CHAPTER FOUR

DISCUSSION

4.1 Frequency

We indicate to the signal produced by second as frequency. The stimulation frequency values depend on the type of therapy desired, but most types use 20-50Hz patterns for best results (Baker & McNeal, 1988). Higher Frequencies are generally more comfortable because they cause tingling feeling instead of tapping in low frequencies (Sluka & Walsh, 2003).

4.2 Ramping of stimulation frequency

Ramp time indicates the actual time that the stimulation has turned on until the desired frequency is reached. it can be applied when the stimulation of more than one muscle is required. (Bijak & rakos, 2005).

4.3 Pulse width/Duration

Electric muscle stimulation devices can produce signals based on a geometric shape such as square, peaked, or sine wave. They indicate the amplitude of the electric current above a zero-standard line, and alternating one, above and beneath the line. Time duration of a single pulse is defined as width or pulse length. width can be increased and decreased based on our desire to recruit more muscle fibers (Lagerquist & Collins, 2010).

4.4 Amplitude/Intensity

We refer to the amount of the current used to stimulate the muscle by the intensity and its defined by (mA).

4.6 Dosing of the stimulation

Dosing of EMS programs variations are dependent on the muscle being stimulated, parameters used, and the aim of the treatment. Studies showed that the duration of the session was not

dependent on the duration, whether the duration is long or short its mostly relying on the type of the muscle and the type of the therapy. (Trasher & popovic, 2008).

CHAPTER FIVE

CONCLUSION

Electric muscle stimulation devices are used in a wide range of treatments, but their effectiveness still needs improvements, and further scientific researches must be made to shape high resolution new EMS devices generation. in our research, we tried to develop a simple EMS device based on microprocessor chip and microcontroller, further work is to enhance the ability of the device to predict if the pulses are being targeted the exact harmed muscle fibers by adding bio impedance measurement and connect it to the Arduino as processed input. also, expanding the frequency range and the voltage value must be done so the treatment can be applied on multiple muscle types.

CHAPTER SIX

FUTURE WORK

Future improvement for our portable EMS device is to add bio impedance measurement integrated circuit. In the following section, the theoretical and practical aspects to achieve this goal are explained.

6.1 Bio-impedance background

Bioimpedence is The assessed response of any biomaterial (e.g., the full total body, skin area, muscle, extra fat, or blood vessels), either deceased or living, for an applied current. Bioimpedance identifies the passive electrical power properties of biomaterial, and changes in the bioimpedance can indicate changes in the biomaterial (e.g., changes in drinking water content, changes in the blood circulation, anxious activity, galvanic pores and skin response). The bioimpedance is a intricate quantity, the reason behind it is because the biomaterial not simply oppose the applied current move, it also phase-shifts the voltage with regards to the current in the time-domain brought on by the built-in capacitances at the cell membranes. Your body become a conductor in blend with the capacitance of the cell membranes. The area of the body adding most to the conduction process is known as system.drawing.fat free mass (FFM). Furthermore, we have system.drawing.fat mass (FM) which only contribute just a little to the electrical conduction process. In case the FFM is set from measurements, then FM is distributed by the total bodyweight without the FFM. In the FFM we've one part from the extracellular water (ECW), another part intracellular water (ICW), the proteins and the bone composition with minerals. The full total body drinking water is the total of ECW (extracellular normal water) and ICW (intracellular drinking water). Your body cell mass (BCM) which is the protein enhanced area of the is not damaged in catabolic state governments. The task is to make measurements allowing the perfect determination of the different compartments of your body

6.2 Electrical properties of tissue

We call the conductivity of the body ionic because pf the ions in the intra-extra cellular liquid. The most important ions are Cl^- and Na^+. In regular electronics, electric conductivity in metal is the flow of free electrons in the atomic level, our bodies conduct electrons in such a different way because the conduction method is about the transportation of the ions in the intra- and extracellular liquid. This will result in concentration changes. Tissue is composed of cells, and these cells have unipolar membrane, consisting of two layers of phospholipid, this phospholipid has polar head, but the two tails are consisting of fat and therefore its unipolar, which makes the membrane a wicked conductor for ions. This will give the cell the ability to store electrons which

we call it capacitance ability. Because of ability of the cells, tissue can be seen on as a dielectric (but also can be seen as a conductor, muscle tissue is more like a conductor with capacitive properties, while internal organs are more like a dielectric with some conducting properties).

6.3 Bioimpedance measurement based on the integrated circuit AD5933

The system we intend to build will take in consideration everything starting from taking the measurement ending with the display of final results. Figure1 shows a block diagram for the main modules of the bioimpedance measurement system consisting of the AD5933 card, a microcontroller for communication with the AD5933, and a laptop (PC) communicating with the microcontroller and presenting results. The software will be including the microcontroller calculations and the PC interface. Peripheral connections to the device are also included.

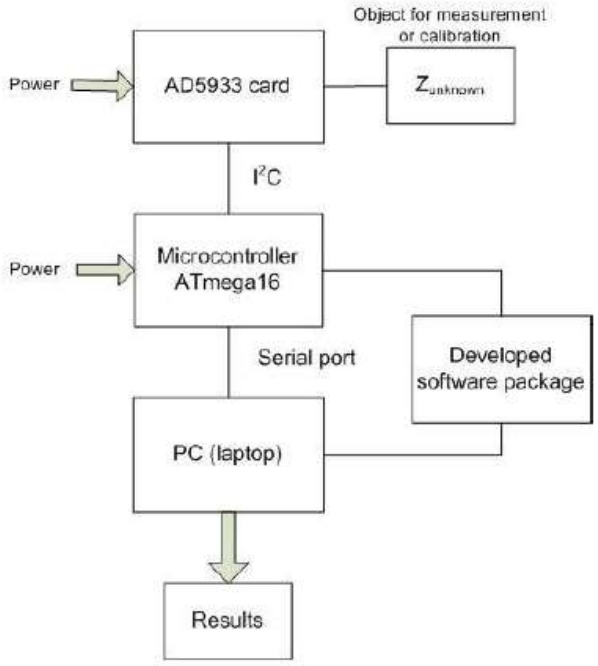

Figure 6: Main modules of the bioimpedance measurement system

6.4 The AD5933 integrated circuit and its functionality

The AD5933 has a high precision impedance converter system with an internal converter system and an internal DDS (Direct Digital Synthesis) frequency generator for the delivery of the signal used for excitation of the impedance being tested. The response signal from the impedance will be amplified and then sampled by a 12 bit analog to digital Converter. The system can take impedance measurements starting from 0.1k to 10M OHM.

6.5 Discussion

To employ skin impedance to muscle state, we make exogenic excitation for skin cells by connecting two carrying current electrodes and two picking up electrodes. The first two carrying electrodes will send continuous current through the skin surface, which to be measured as voltage change in the system. The second picking up electrodes will receive readings from skin surface as voltage changes. After the reading of the bio feedback information, there will be analyzation for those values based on a simple algorithm which will compare them with predetermined values and decide whether to change the intensity, timing, and signal shape.

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APPENDICES

Arduino Code:

```
#include <LiquidCrystal.h>


const int buttonPin_1 = 8;

const int buttonPin_2 = 9;

const int buttonPin_3 = 10;

const int ledPin =  13;


LiquidCrystal lcd(12, 11, 5, 4, 3, 2);


 int buttonState_1 = 0;

 int buttonState_2 = 0;

 int buttonState_3 = 0;


void setup() {

  lcd.begin(16, 2);

  pinMode (buttonPin_1, INPUT);

  pinMode(buttonPin_2, INPUT);

  pinMode(buttonPin_3, INPUT);

  pinMode(ledPin, OUTPUT);
```

```
  Serial.begin(9600);
}

void loop() {

   buttonState_1 = digitalRead(buttonPin_1);

  if (buttonState_1 == HIGH)
  {
  lcd.setCursor(0, 1);
  lcd.print("first signal");
  lcd.setCursor(0, 0);
  lcd.print(millis() / 1000 );
  lcd.print("  sec");
  //delay (1000);
  Serial.print("HIGH");
   digitalWrite(ledPin, HIGH);
    delay (100);
    digitalWrite(ledPin, LOW);
    delay (900);
  }
```

```
 buttonState_2 = digitalRead(buttonPin_2);
if (buttonState_2 == HIGH) {
    lcd.setCursor(0, 1);
  lcd.print("Second signal");
  lcd.setCursor(0, 0);
  lcd.print(millis() / 1000 );
  lcd.print("  sec");
  //delay (1000);
  Serial.print("HIGH");
    digitalWrite(ledPin, HIGH);
    delay (500);
        digitalWrite(ledPin, LOW);
    delay (500);

  }

  buttonState_3 = digitalRead(buttonPin_3);
if (buttonState_3 == HIGH) {
 lcd.setCursor(0, 1);
  lcd.print("Third signal");
  lcd.setCursor(0, 0);
  lcd.print(millis() / 1000 );
```

```
  lcd.print("  sec");
  //delay (1000);
    digitalWrite(ledPin, HIGH);
    delay (200);
        digitalWrite(ledPin, LOW);
    delay (300);
}
  if ( (buttonState_1 == LOW)&&(buttonState_2 == LOW)&&(buttonState_3 == LOW) )
  //else
  {
    //lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("STOP                ");
  digitalWrite(ledPin, LOW);
  }



}
```