ELECTRO-PHYSIOTHERAPY

A GRADUATION PROJECT SUBMITTED TO THE FACULTY OF ENGINEERING OF NEAR EAST UNIVERSITY

By

MUHAMMAD MUNZER ALSEED

MHD BELAL KHABBAZ

In Partial Fulfillment of the Requirements for The Degree of Bachelor of Science in Biomedical Engineering

NICOSIA, 2017

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

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ABSTRACT

Muscle and nerve stimulation using electrical currents has proven its efficiency in medical and athletic cases, due to its accuracy, ease of use, and high controllability. This project aims to produce electrical currents with different shapes to be used in electro physiotherapy for many physiological cases (TENS or EMS based stimulation). The signals are generated by two wave generators, where one of them is chosen by the user using the touch screen. It is then applied on one of two linear amplifiers to get the required amplitude, and then to the output electrodes.

We have merged two devices in one (EMS with TENS), with a wide range of different frequencies. We've also prepared fixed programs for medical conditions so that the device can be used by people without an experience in the details of physiotherapy, or in emergency cases. There is also a manual program to be used by experts. Above all, we have facilitated a much better user interfacing, using an LCD touch screen, with an embedded smart application that resembles a smart phone application, and makes it easier for the users to use.

Keywords: Muscle stimulation; Nerve stimulation; Touch screen; Adjustable frequency; Amplification.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CNS: Central Nervous System

EMS: Electrical Muscle Stimulation

Hz: Hertz

IC: Integrated Circuit

LCD: Liquid Crystal Display

PNS: Peripheral Nervous System

PT: Physical Therapy

TENS: Transcutaneous Electrical Nerve Stimulation

CHAPTER 1
INTRODUCTION

The human body contains more than 650 different muscles, all under the control of the nervous system. These muscles are sometimes subject to injuries, or require some sort of rehabilitation due to immobilization after surgeries, or need to improve their strength, and this is all done by physiotherapy, which includes many techniques and methods, and one of them is electrical stimulation. Our project aims to use electrical currents of different frequencies and amplitudes, to stimulate muscles and use that in physiotherapy. Our main aim is to take a higher step and merge both Electrical muscle stimulation (EMS) and Transcutaneous electrical nerve stimulation (TENS) in one device that can be easily controlled and set by the user to get the required shape of current. It's also equipped with sets of pre-programmed settings for multiple cases (Both EMS and TENS) so that the device can be used by people without a deep experience in the details of physiotherapy, or in emergency cases. Moreover, it has a touch screen with an application to facilitate a better user interfacing and make it much easier to use. The signals are produced by a main power supply, modified and stored in the memory of a microcontroller, then outputted to the electrodes of the device.

Figure 1.1: Muscular system

CHAPTER 2

LITERATURE REVIEW

2.1 Nervous System

The nervous system consists of billions of neurons in constant touch with each other for the purpose of monitoring and regulating the internal and sensory functions. The central nervous system, or CNS, includes the brain and spinal cord, and the peripheral nervous system, or PNS, includes all the nerves outside the central nervous system. The spinal cord behaves like an information superhighway, speeding signals from the brain to the PNS and vice versa. Like the muscular system, the PNS, consisting of all the roads that ultimately lead to the superhighway, has a dual function. One part is somatic, meaning under conscious control, and the other is autonomic, or outside of conscious control for controlling the necessary muscles.

When the messages arrive, a chemical, acetylcholine, is released from the nerve endings, stimulating the membranes of muscle fibers and causing them to contract. It feels as though this happens instantly, but in fact, it takes about 1 millisecond -- 1/1000 of a second. Normally, your conscious mind is unable to speed up or slow down your heart rate, digestion or other visceral muscles because these are regulated autonomically (Purves et al, 2001).

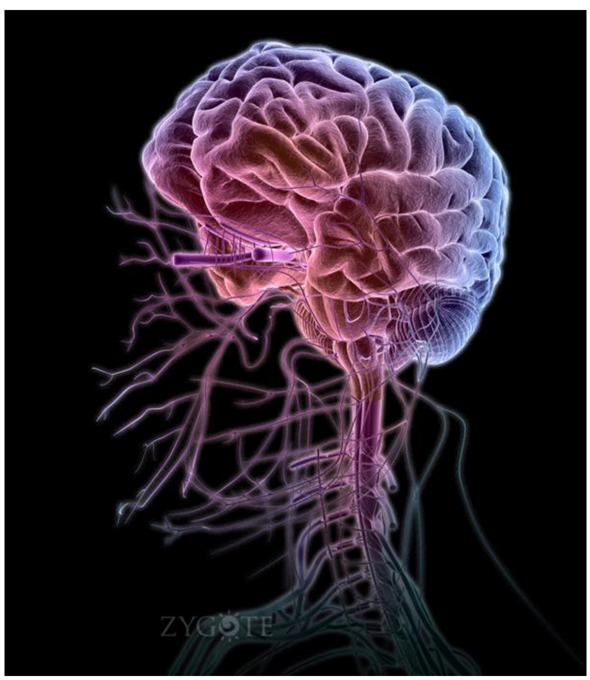

Figure 2.1: Nervous system

2.2 Muscle-Nerve Communication

Actions such as leaning over and picking up a dropped pen involve the coordinated effort of numerous muscle groups. Your conscious mind relays this command to your CNS, which translates it into electrical impulses. These are then channeled through the somatic part of your PNS to the nerves responsible (Milner-Brown, Stein and Yemm, 1973).

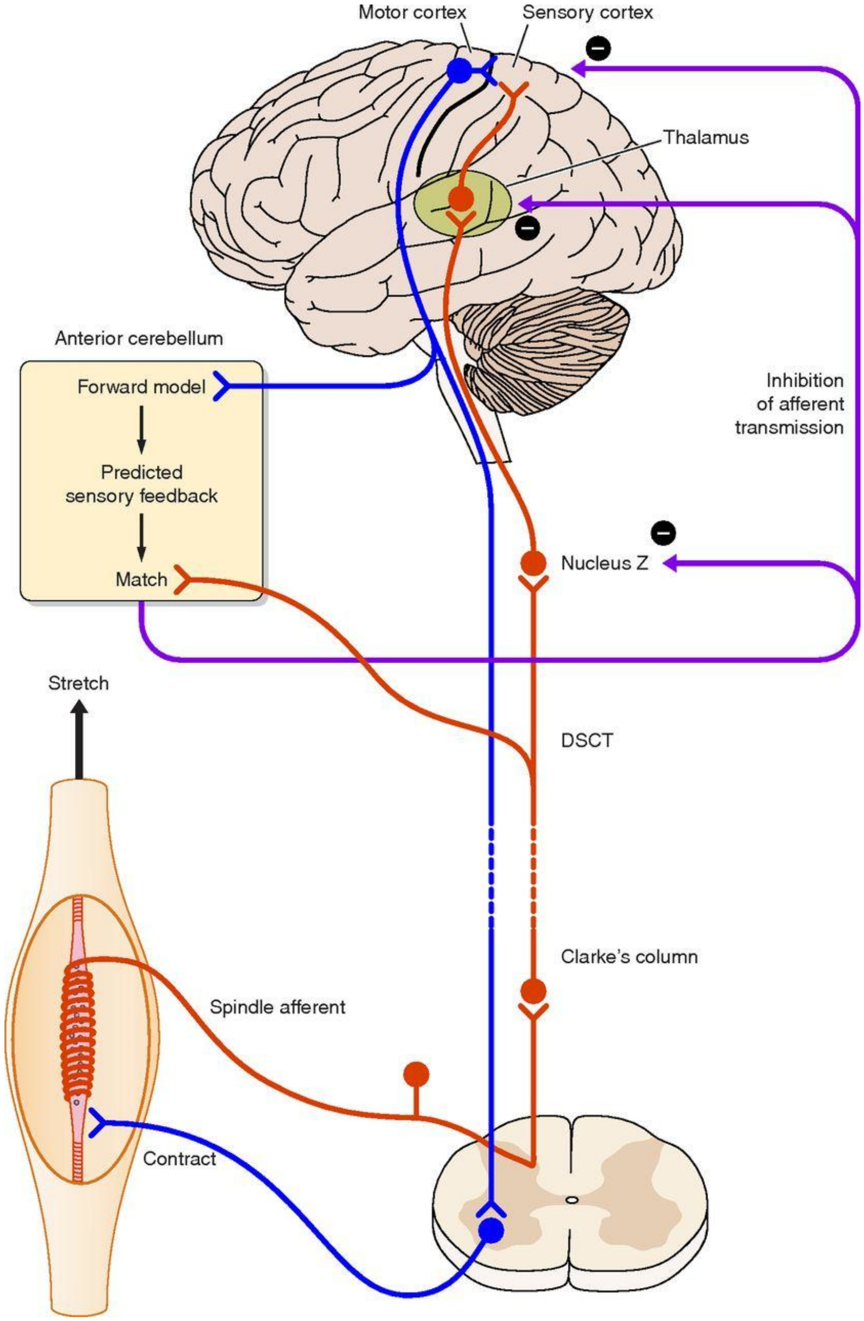

Figure 2.2: Muscle-Nerve Communication

2.3 Muscles and Movement

Skeletal muscle contractions are neurogenic as they require synaptic input from motor neurons to produce muscle contractions. A single motor neuron is able to innervate multiple muscle fibers, thereby causing the fibers to contract at the same time. The contraction produced can be described as a twitch, summation, or tetanus, depending on the frequency of action potentials. In skeletal muscles, muscle tension is at its greatest when the muscle is stretched to an intermediate length as described by the length-tension relationship (Kent, 1987).

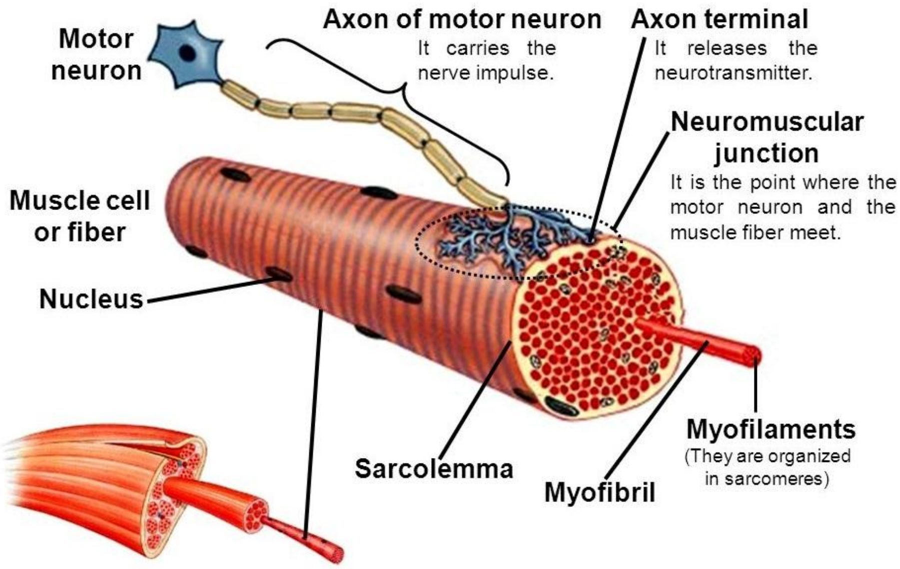

Figure 2.3: The neuromuscular junction

2.4 Physiotherapy

Physiotherapy or Physical therapy (often abbreviated to PT) is a physical medicine and rehabilitation specialty that, by using mechanical force and movements, remediates impairments and promotes mobility, function, and quality of life through examination, diagnosis, prognosis, and physical intervention.

Greek Physicians are believed to have been the first practitioners of physical therapy. The earliest documented origins of physiotherapy as a professional group date back to Per Henrik Ling, who founded the Royal Central Institute of Gymnastics (RCIG) in 1813.Modern physiotherapy was established in Britain towards the end of the 19th century (Atiken, 2007)

2.5 Uses of physiotherapy

Physiotherapy can help in preventing muscle wasting and joint mobility; **i**mmobilization after surgery, especially in elderly patients can lead to joint stiffness and muscle weakness. The physiotherapist gives general strengthening and mobilizing exercises to regain mobility.

It's also helpful to treat a chronic conditions or neurological diseases; conditions which severely affect the patient's movements like cerebral palsy, Parkinson's disease, Substantia Nigra, spinal cord injuries and stroke. Although physiotherapy does not heal the disease or even slow down the disease process, it does increase the quality of life, helps the patient become independent and live as normal a life as possible.

Other cases can be also treated by physiotherapy, including injuries while playing, people who live with chronic pain, thrombosis, pressure sores, or during and after surgeries (Maffiuletti, 2006).

Figure 2.4: Joint pain

2.6 Muscle Stimulation

It is essential to understand that the muscle contracts when it gets a signal from the brain via the nerve, hence the need for artificial or assisted contraction arises when there is something wrong with this neural network or we want to enhance the efficiency of these signals.

In case of weak or paralysed muscles, what a muscle stimulator does is that it creates the impulse by bypassing the nerve and by giving the muscle just the amount of push it requires to cause a contraction.

There are two types of signals to stimulate in the body:

1- EMS, which stands for Electrical muscle stimulation.

2- TENS, which stands for Transcutaneous electrical nerve stimulation.

The EMS focuses on the muscle rather than the nerve ending. EMS uses a cycle of stimulations, contraction and then relaxation at intensities from 1 to 130Mh to increase blood flow to the area, which decreases inflammation and promotes healing and muscle growth. By stimulating the muscles at their basic structure, an EMS unit causes muscle contractions similar to those obtained by exercise.

2.7 Examples of General Procedures in EMS

These are some examples of the parameters that should be set in three different cases of EMS (Gallo, 2009):

<u>Endurance Training:</u>

- Program: Synchronous
- Frequency: 15 Hz
- Pulse Duration: 150 μs
- Ramp: 2 seconds
- Contraction Duration: 6 seconds
- Pause: 3 seconds
- Application Duration: 30 minutes, followed by longer pauses

Rule of Thumb:

- Lower Frequency: Max. 15-18 Hz
- Short Contraction Duration: 4-6 seconds
- Short Pause Time: 3-6 seconds
- Long Application Duration: 20-30 minutes
- Small Muscle: Low pulse width (50 – 100 μs)
- Large Muscle: Higher pulse width (200 – 300 μs)

Elasticity Training:

- Program: Synchronous
- Frequency: 40 Hz
- Pulse Duration: 200 μs
- Ramp: 2 seconds
- Contraction Duration: 10 seconds
- Pause: 15 seconds
- Application Duration: 5 minutes; may be repeated several times daily. Optimisation is possible through small changes in frequency and placing of electrodes.

Muscle Build-up Training:

- Program: Synchronous
- Frequency: 45 Hz
- Pulse Duration: 300 μs
- Ramp: 3 seconds
- Contraction Duration: 15 seconds
- Pause: 15-30 seconds
- Application Duration: 3-5 minutes; may be repeated several times daily.

Rule of Thumb:

- Higher Frequency: 35-50 Hz
- Longer Contraction Duration: Over 10 seconds
- Pause Time: At least as long as the contraction duration
- Short Application Duration: 3-5 minutes; several repetitions daily
- Small Muscle: Low pulse width (50-100 μs)
- Large Muscle: Higher pulse width (200-300 μs).

CHAPTER 3
MATERIALS AND METHODS

3.1 The Aim of The Project

This project aims to produce electrical currents with different shapes to be used in electro physiotherapy for many physiological cases (TENS or EMS based stimulation). The signals are generated by two wave generators, where one of them is chosen by the user using the touch screen. It is then applied on one of two linear amplifiers to get the required amplitude, and then to the output electrodes.

As we saw earlier, TENS is used for acute or chronic pain, while EMS devices are used to focus on the muscle, and used for training and many other uses (mentioned previously). TENS or EMS usually require profession in use, so for commercial uses it is better to write programs to make normal users select the required settings from a prepared menu, and besides having default programs it’s also needed to have the ability to modify the frequency of the wave which is used for muscle or nerve stimulation. So users (expert & normal) can get the best of both worlds with such a device that combines EMS with TENS.

An example of somebody who could benefit from a TENS and EMS combination unit is an active sportsperson who works at a desk and suffers from lower back pain. They would be able to use the TENS function to relieve their back pain and the EMS could be used to help strengthening their muscles as part of their training program.

A combination unit would be a desirable alternative for anybody who wants to use both TENS and EMS. It means that they only need to purchase a single device, versus two separate ones.

The other advantage of having a single device is portability. People who like to take their device on vacation, when they’re away on a business trip, visiting friends, etc. only have to carry one device**.**

3.2 Working Principle

The power supply feeds the microcontroller, the LCD screen, the signal generators, and the amplifiers. The microcontroller is programmed to communicate with the touch screen and receive instructions with each click, where one among six of its pins is set high for each one of the programs. Each one of the 2 signal generators produces 3 shapes of the signal: sinusoidal, square, and triangular, so we have six signals in total, 3 of them are used for EMS, 2 for TENS, and one has an adjustable frequency for the manual program. The signal then is augmented by one of two amplifiers to the effective value depending on its type (EMS or TENS), and directed to the electrodes that are fixed on the surface of the skin for EMS, or inserted under the skin as needles for TENS.

3.3 The Block Diagram

We can distinguish 7 main blocks in the device :

1. Power supply : which provides the required voltage for the other component of the device.

2. Microcontroller : which controls the output of the electrodes according to the user's desires.

3. Signal generators : 2 ICs of the type ICL8038 that produce 3 different shapes of periodic signals.

4. Amplifiers : Two 741-type op-amp ICs which augment the output of the signal generators.

5. LCD touch screen : to display the information and control the output of the microcontroller.

6. Electrodes: which deliver the signal from the device to the muscle or the nerve.

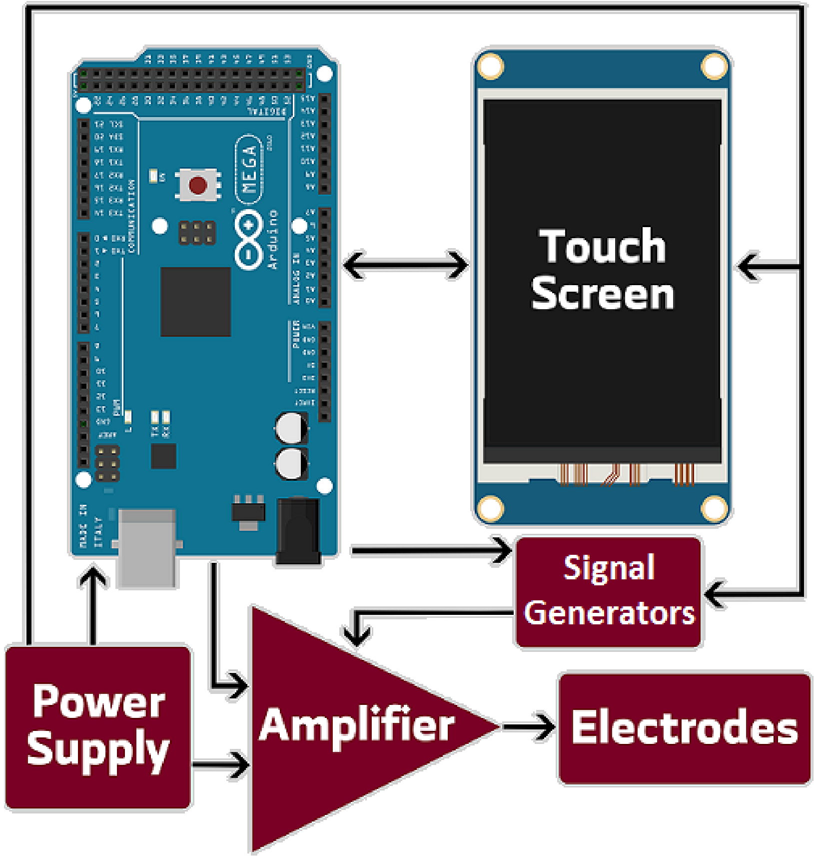

Figure 3.1: Block diagram

3.4 Components

3.4.1 Power supply

The power supply is the main source of signal that is adjusted later. It's also important to feed the LCD, the amplifiers, and the microcontroller. A 15 volt battery is the requirement to feed the signal generators.

Figure 3.2: Power supply

3.4.2 Microcontroller

The microcontroller is responsible of controlling and selecting the specific signal. Here we are using Arduino MEGA microcontroller. The reason of using it is because it is an open source software and hardware, and it's cheap, easy to use, and easy to program. In addition, it has 54 I/O pins, which allows adding much more signals for future improvements. Moreover, it has 4 Transmit/Receive pins, to use one set with the screen, and another one for debugging. The uploaded program is written with C, and it includes the codes that allows the user to interface by the LCD display.

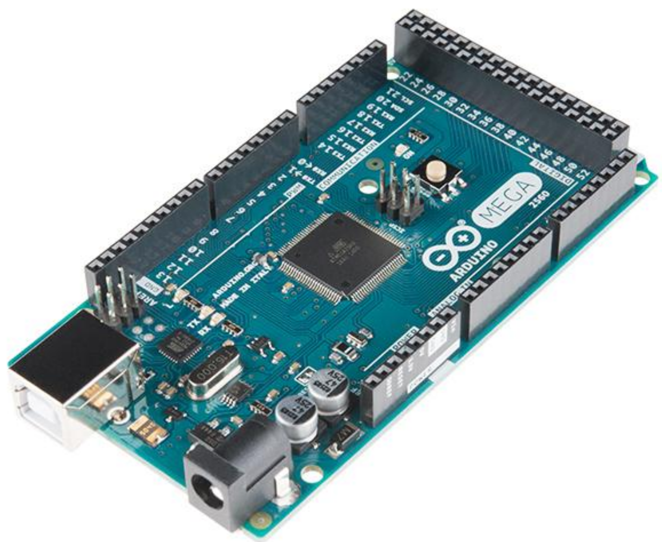

Figure 3.3: Arduino MEGA

3.4.3 Signal Generators

Here, we are using ICL8038 microchip, which is a function generator that produces 3 shapes of the signal: sinusoidal, square, and triangular. We are using 2 chips, so we have six signals in total, 3 of them are used for EMS, 2 for TENS, and one has an adjustable frequency for the manual program, namely a sinusoidal one, where the frequency is dependent on a certain variable resistor, which is accessed by the user directly. We use the proper capacitors, resisters, and diodes to obtain the right signals.

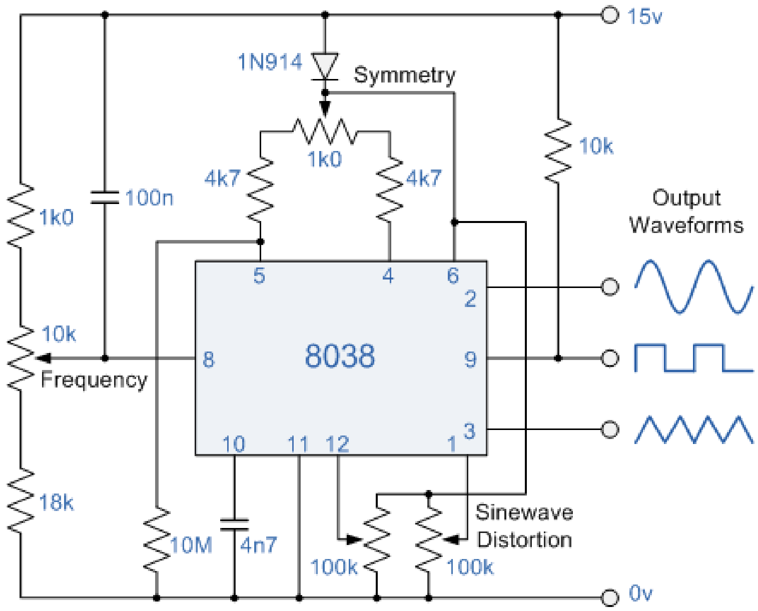

Figure 3.4: ICL8038 connections

3.4.4 Amplifiers

Here we are using two 741-type op-amps, one for EMS signals, and the other for TENS and manual program. We use a high amplification for EMS, and a low one for TENS. This operational amplifier augments the signal to a certain extent, and its internal circuit design is shown in figure 3.5.

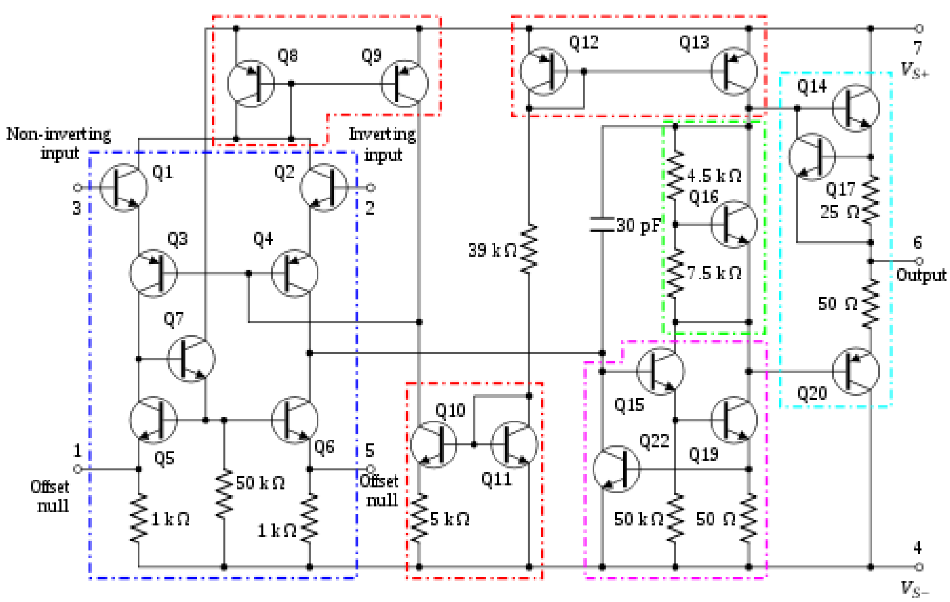

Figure 3.5: 741 op-amp internal circuit design

3.4.5 LCD Touch Screen

We are using Nextion NX4832T035: a 3.5 inch LCD touch display, colorful, with 480x320 resolution. We choose to use a touch screen to improve the user interfacing, and get rid of the complications of the pushbuttons. It's easily programed using a desktop software, and has its own codes for each page of the embedded application .It also has its own library to communicate with the Arduino.

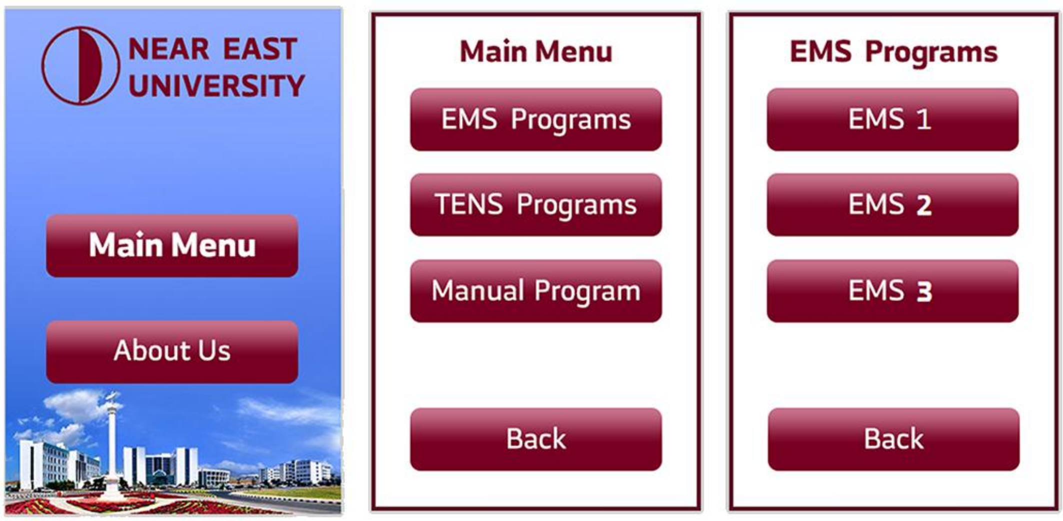

Figure 3.6: User interface examples

Figure 3.7: Nextion NX4832T035 LCD touch display

3.4.6 Electrodes

For EMS, they pads are placed on the surface of the skin to deliver the signal from the device to the muscle. Many types of electrodes can be used, and the can be changed be the user. They are often disposable, with the ability to use them several times before getting rid of them. Their sizes vary according to the muscles to be stimulated. For TENS, needle-type electrodes are used, to deliver the stimulation to the nerve directly under the skin.

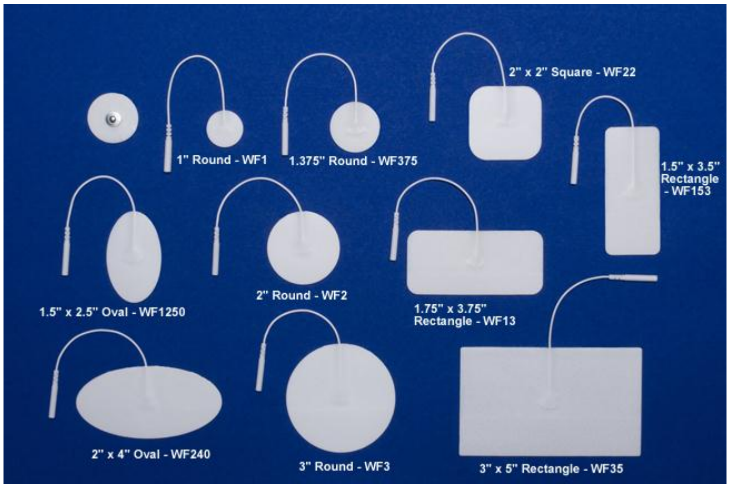

Figure 3.8: Electrodes used in EMS

3.5 Software Implementation

We have programed the Arduino to communicate with the touch screen, and included While loops in its sketch, one for each program. Each loop selects a particular Arduino pin, and loops into repeated 1 second pulse and 5 seconds rest. The Nextion library is included to access the touch screen. The full sketch of the Ardunio is shown in Appendix 1.

CHAPTER 4

PRICE ESTIMATION AND COMPARISON

4.1 Price Estimation

The total price of our device cannot be given a determined value, it depends on the available electric component in the local store. However, we can estimate an average price.

First, we need to calculate the cost of our device (prices are according to Amazon.com).:

Component	**Price**
Arduino MEGA	35 $
2 signal generators	5 $
Amplifier	5 $
LCD touch screen	30 $
Electrodes	20 $
Resistors, capacitors, connecting wires. PCBs	20 $
Estimated Cost	**115 $**

Tablel 4.1: Separate components costs

Suppose that we need a profit of nearly 30%, the average price will be about **150$** .

4.2 Comparison

Here are some available EMS and TENS devices in the market with their prices, so we can compare them to our device :

TENS DEVICES	**EMS Devices**	**TENS & EMS**
truMedic TENS Unit Electronic Pulse Massager (110$)	Electronic Pulse Muscle Stimulator Massager Machine (300$)	Twin Stim Plus 3rd Edition - Unit (200$)
SUNMAS SM9128 (50$)	Electronic Acupuncture Treatment Instrument (60$)	InTENSity (150$)
iReliev Tens Unit (70$)		The Omega Tens & EMS Combo Unit for Ultimate Pain Relief (600$)
Pure Enrichment PurePulse Pro TENS Unit (90$)		Twin Stim Plus Digital TENS and EMS Unit (2nd Edition) | DS5002 (350$)

Tablel 4.2: Price comparison with similar devices

CHAPTER 5
INTERVIEW

We met Dr. Ibrahim Khabbaz via internet and we asked him some questions related to electrical stimulation in the hospitals in his vicinity (Saudi Arabia):

1. Is it good for the doctors and physicians to merge both EMS and TENS?

> It will be helpful for experts and non-experts to use it better than using two separate devices, because that gives the advantage of portability, and lowering the cost of having two devices, so that buying one device would be enough for people with multiple probems. Moreover, These devices are not that dangerous, I mean they don't cause electrical shocks due to bad usage, so it will not be a problem if we combine them together.

2. Is it helpful to implement a database in the device that contains different cases of treatment to be chosen by the user?

> Of course, as I mentioned before, EMS and TENS is not harmful, and this step of programmed settings would be very useful for people with no experience to apply the currents on themselves at their homes, especially if you cover a wide range of medical cases so everybody can access it.

3. Is it helpful to program the device to detect the diseases and treat the patient based on the database?

> Actually, this step needs an implemented artificial intelligence in the device, with high performance sensors and very complicated noise filtering techniques, and that is not necessary if we already know the problem, where this is often the case , so I wouldn't prefer to add all this complexity to the device, which is going to cost multiples of the actual cost.

CHAPTER 6
DISCUSSION

6.1 Improvements in Our Device

We have merged two devices in one (EMS with TENS), with a wide range of different frequencies. We've also prepared fixed programs for medical conditions so that the device can be used by people without an experience in the details of physiotherapy, or in emergency cases. There is also a manual program to be used by experts. Above all, we have facilitated a much better user interfacing, using an LCD touch screen, with an embedded smart application that resembles a smart phone application, and makes it easier for the users to use.

6.2 Advantages of Our Device

1. The device can be used for muscle or nerve stimulation.

2. It's portable, so the user can take it anywhere.

3. It has a low cost compared to other devices.

4. It can be used by non-experts or experts.

5. It has a smart and easy user interface.

6.3 Disadvantages of Our Device

The fixed programs cannot tell which particular case it deals with, because it depends on the degree of the injury, the patient’s age, and other factors. Hence, the patient should consult an expert before starting a program.

6.4 Future Visions and Perspectives

We can show the steps of applying the device on the patient on the LCD screen. We can also implement artificial intelligence so that it can detect the problem and output the proper currents accordingly. It's also possible to implement a Bluetooth device so it can be controlled wirelessly.

CHAPTER 7
CONCLUSION

Stimulation of muscles using electrical currents has proven its efficiency in medical and athletic cases, due to its accuracy, ease of use, and high controllability. Our project focuses on this point, and tries to combine almost all the available techniques of muscle stimulation by electrical currents in one device, namely EMS with its various uses in different cases, and TENS. This allows people with different problems to use one device with integrated properties. The pre-programmed settings also allow non-experts to use the device in few clicks on the smart touch screen, and make it easier for users to use the device in their homes efficiently without the help of a physician.

Electrical currents are well-studied and their properties can be easily changed, this allows us to take this advantage and use it in our device to give accurate outputs that might be better than manual massages.

EMS and TENS are simply among the best ways in rehabilitation, reducing pain, and training, and combining them in one device is such a great advantage that many people may need.

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APPENDICES

Appendix 1

ARDUINO SKETCH

```
#include "Nextion.h"

/*
 * Declare a button object [page id,component id, "component name"].
 */

NexButton e1 = NexButton(6, 1, "e1");
NexButton s1 = NexButton(7, 1, "s1");
NexButton e2 = NexButton(8, 1, "e2");
NexButton s2 = NexButton(9, 1, "s2");
NexButton e3 = NexButton(10, 1, "e3");
NexButton s3 = NexButton(11, 1, "s3");
NexButton t1 = NexButton(12, 1, "t1");
NexButton s4 = NexButton(13, 1, "s4");
NexButton t2 = NexButton(14, 1, "t2");
NexButton s5 = NexButton(15, 1, "s5");
NexButton man = NexButton(16, 1, "man");
NexButton s6 = NexButton(17, 1, "s6");

int ems1 = 33;
int ems2 = 35;
int ems3 = 37;
int tens1 = 39;
int tens2 = 41;
int manual = 43;
int x=0;

/*
 * Register a button object to the touch event list.
 */
NexTouch *nex_listen_list[] =
{
```

```
    &e1,
    &s1,
    &e2,
    &s2,
    &e3,
    &s3,
    &t1,
    &s4,
    &t2,
    &s5,
    &man,
    &s6,
    NULL
};
/*
 * Button component pop callback function.
 */
void e1PopCallback(void *ptr)
{    x=1;
}

void s1PopCallback(void *ptr)
{    x=0;
}

void e2PopCallback(void *ptr)
{    x=2;
}

void s2PopCallback(void *ptr)
{    x=0;
}

void e3PopCallback(void *ptr)
{    x=3;
}
```

```
void s3PopCallback(void *ptr)
{    x=0;
}

void t1PopCallback(void *ptr)
{    x=4;
}

void s4PopCallback(void *ptr)
{    x=0;
}

void t2PopCallback(void *ptr)
{    x=5;
}

void s5PopCallback(void *ptr)
{    x=0;
}

void manPopCallback(void *ptr)
{    x=6;
}

void s6PopCallback(void *ptr)
{    x=0;
}

void setup(void)
{
    pinMode(ems1, OUTPUT);
    pinMode(ems2, OUTPUT);
    pinMode(ems3, OUTPUT);
    pinMode(tens1, OUTPUT);
    pinMode(tens2, OUTPUT);
```

```
    pinMode(manual, OUTPUT);
    digitalWrite(ems1, LOW);
    digitalWrite(ems2, LOW);
    digitalWrite(ems3, LOW);
    digitalWrite(tens1, LOW);
    digitalWrite(tens2, LOW);
    digitalWrite(manual, LOW);
    nexInit();

    /* Register the pop event callback function of the current button
component. */
    e1.attachPop(e1PopCallback, &e1);
    s1.attachPop(s1PopCallback, &s1);
    e2.attachPop(e2PopCallback, &e2);
    s2.attachPop(s2PopCallback, &s2);
    e3.attachPop(e3PopCallback, &e3);
    s3.attachPop(s3PopCallback, &s3);
    t1.attachPop(t1PopCallback, &t1);
    s4.attachPop(s4PopCallback, &s4);
    t2.attachPop(t2PopCallback, &t2);
    s5.attachPop(s5PopCallback, &s5);
    man.attachPop(manPopCallback, &man);
    s6.attachPop(s6PopCallback, &s6);

}

void loop(void)
{
    nexLoop(nex_listen_list);

    if(x==1) {
    digitalWrite(ems1, HIGH);
    delay(1000);
    digitalWrite(ems1, LOW);
    delay(5000);
    }
```

```
    if(x==2) {
    digitalWrite(ems2, HIGH);
    delay(1000);
    digitalWrite(ems2, LOW);
    delay(5000);
    }

    if(x==3) {
    digitalWrite(ems3, HIGH);
    delay(1000);
    digitalWrite(ems3, LOW);
    delay(5000);
    }

    if(x==4) {
    digitalWrite(tens1, HIGH);
    delay(1000);
    digitalWrite(tens1, LOW);
    delay(5000);
    }

    if(x==5) {
    digitalWrite(tens2, HIGH);
    delay(1000);
    digitalWrite(tens2, LOW);
    delay(5000);
    }

    if(x==6) {
    digitalWrite(manual, HIGH);
    delay(1000);
    digitalWrite(manual, LOW);
    delay(5000);
    }
}
```