Design and Development of Adjustable Halo coil for Non-Invasive Treatment of Brain Disorders

Final Document

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1. Project Overview

1.1 Introduction

Transcranial Magnetic Stimulation (TMS) is a technique in modern medical treatment for brain neurological disorders. By causing depolarization and hyperpolarization in the neurons of human brain, Transcranial Magnetic Stimulation can treat disease such as Parkinson's disease, post-traumatic stress disorder, as well as depression. The principal of TMS is that it uses electromagnetic induction to induce faint electric current in magnetic field to cause some activities of parts of brain.

The last halo coil research groups have already done some major part of this project. But the problem is that they cannot let the coil move up and down to 30 degrees. Also they did not achieve the accuracy requirement. Lots of exposed cables and wires also make less safe for patients and hard to assemble.

1.2   Purpose

The purpose of this project is that we are supposed to design and test a whole new structure of the helmet as well as the motion in order to make the coil move up and down freely within 30 degrees. Also, after we finish designing the machine, we will try to avoid using so many wires to connect each device and provide a wirelessly environment the user. we will also carefully calibrate the functional accuracy to make the result as accurate as possible and meets the requirement.

1.3   Deliverables

The whole new structure of the TMS system will include changes as follow:

i. Remove the two servo motors that placed between the coils

ii. Add a side vertical linear actuator to hold the handle of the coil

iii. New structure that link the new side actuator to the main vertical linear actuator in order that they can move together.

iv. Remove the cable between the Arduino board and computer to a wireless communication environment.

v. Remove the cable between the stimulator and computer to a bluetooth environment.

vi. Add a power supply to supply all power.

2. Requirements

2.1 Functional Requirements

Generate an Electric field of 150 Volts/meter in the brain.

Halo coil can be placed easily though machine.

System can receive commands from computer

Move the helmet up and down freely

Display the magnetic field and movement of helmet at PC interface

2.2 Non-Functional Requirements

Accuracy-Must provide consistent results

Comfort- Must below the patient's body temperature

Variability- Must be able to fit all different size and height of human brain.

Extensibility- Source code for GUI are supposed to be written in a way that function can be easily added or removed.

2.3 Operating Environment

The finished system is intended to operate in a hospital. The user interface and design has to be usable by people with little knowledge of electric and magnetic field, even though they are expected to have significant knowledge in the field of medicine. The system would be tested in laboratories and once the design and results are as desired, human brain testing would be the next step. Once we are entirely sure of it functionality and effectiveness, it will be good to be used on patients for treatment. It is to be noted that the experiments in laboratories as well as on the human brain is to be done under strict supervision and by experts only. Stimulating an incorrect region of the brain can be fatal. To aid professional handling this equipment, it is intended that GUI would make it easier for the coil to move and rotate as desired.

3.   System Description

3.1 System Analysis

The Halo Coil structure was designed to safely support the halo coil during treatment. The previous design failed to do so, as it was bulky and not as stable as desired. Without a redesign of the structure and user interface the design will not function well in the intended operating environment.

3.2   Concept Sketches
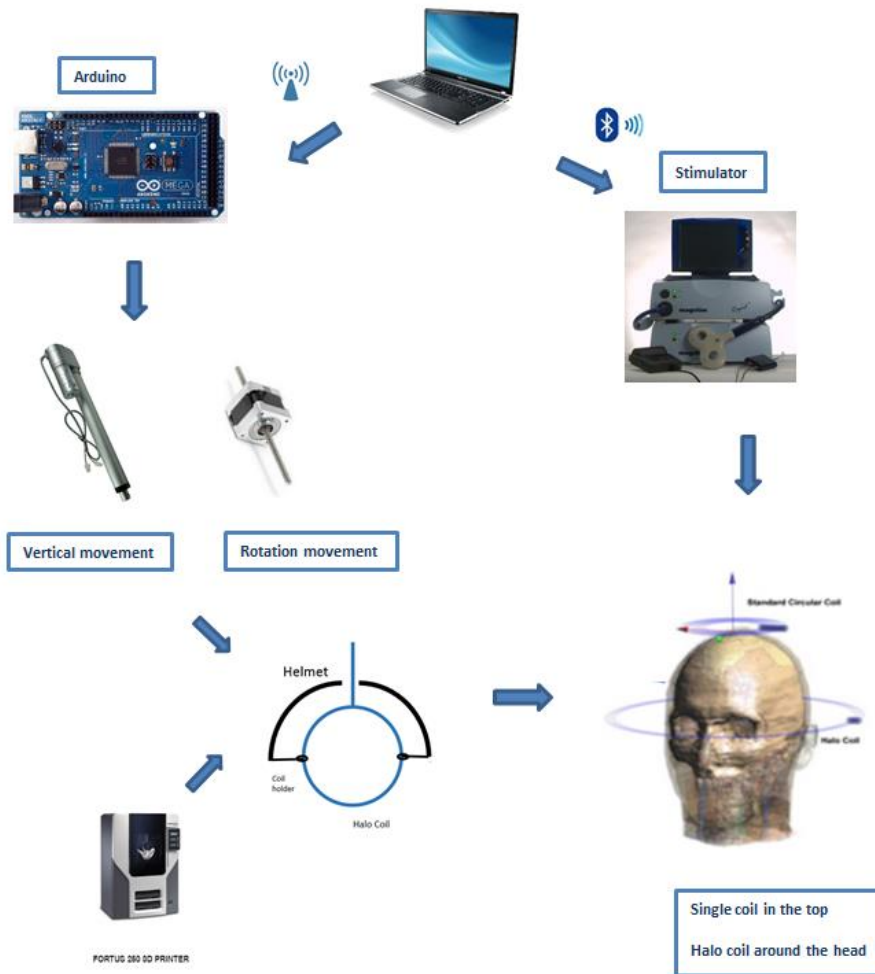

Figure 1: Concept Sketch
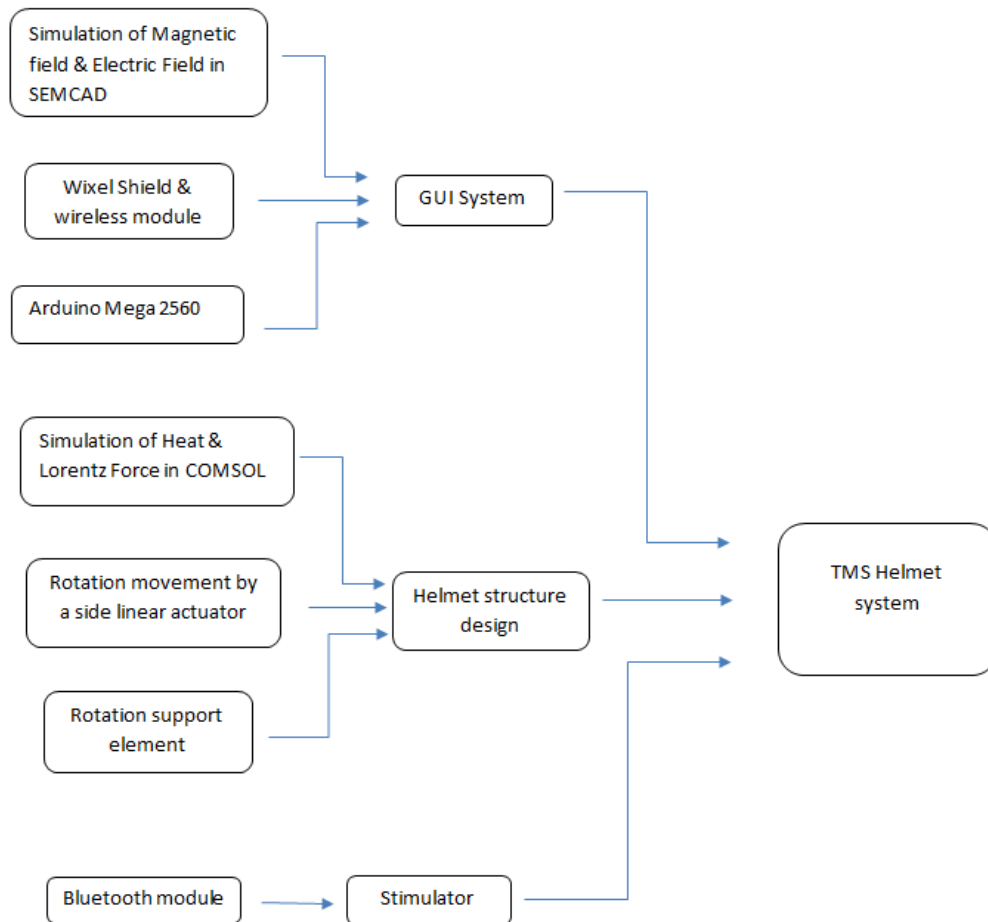
3.3   Block Diagrams

Figure 2: Block Diagram

3.4   Component Specifications

Coil Dimensions

Halo Coil

- Inner diameter: 277 mm
- Outer diameter: 299 mm
- Number of turns: 5 turns

- Space between turns: 1 mm

- Turn width: 6 mm

Helmet dimension

Helmet

- Half circle average diameter: 334mm

- Coil holder diameter: 22mm

Stand system

- Number of linear actuator: 2

- Rotation center to the side actuator: 12- ¼ in

4.   Design Process

4.1 Electric and Magnetic Simulations

Introduction-

We use a software called SEMCAD to find the impact of electric current and magnetic field in deeper regions of the brain. Using SEMCAD we can run various simulations which can help identify the region where the current is maximum due a certain position of the halo coil.

Procedure-

A heterogeneous model of a simple human head is used for simulations. Two coils are placed above it, a single coil and a halo coil. The standard coil, is at the top and is stationary, while the halo coil can be moved and rotated to a certain extent for reaching deeper regions of the brain. The single coil is 90 mm in diameter, having 14 turns. The halo coil has a diameter of 290mm and has 5 turns. The single coil is placed at a distance of 5mm over the head and the distance between both the coils is 10cm. The movement

of halo coil is restricted to 30 degrees upwards as well as downwards. The simulations give us data points using which we can identify the area where electric field is maximum as desired.

Some Simulation Results-

Model- Halo coil- 1cm vertical movement upwards and 0 degrees coil rotation.

Magnetic Field- right side view   Electric   Field-   right   side   view
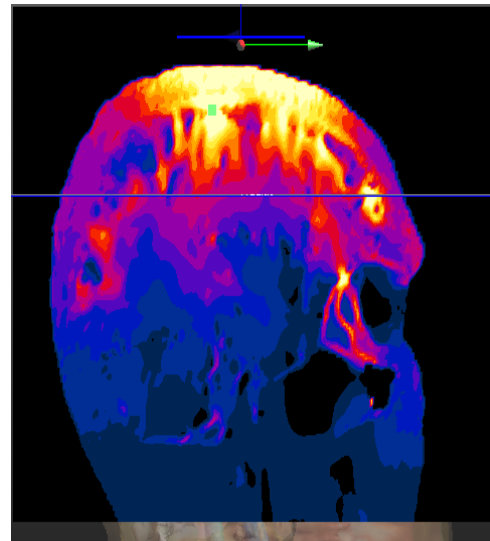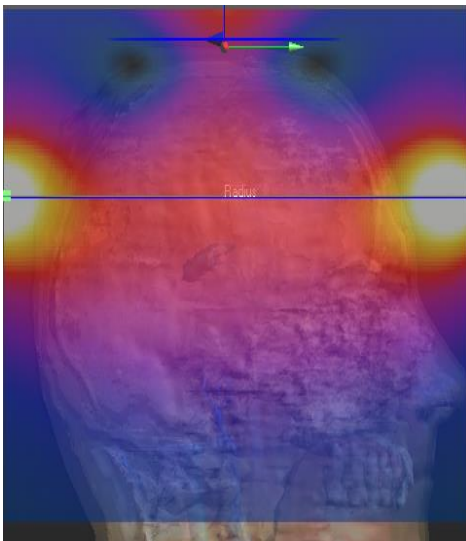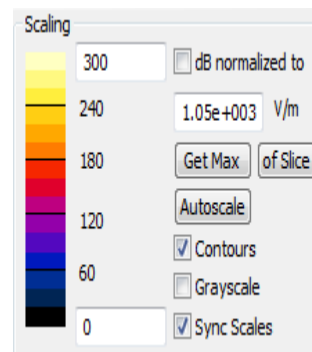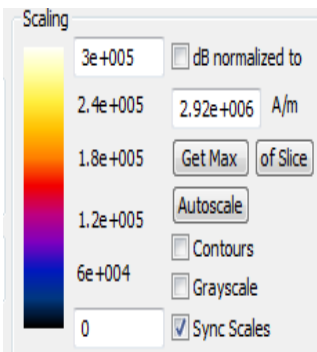

Figure 3: Simulation results for 1cm vertical movement upwards and 0 degree rotation

Magnetic field simulation scale   Electric field simulation scale

4.2 Materials Selection

3D Printing Locations

Boyd Lab (Iowa State University Hoover Hall 1260)
i.   **Dimension uPrint Plus 3D Printer**
      Maximum Size: 8" x 6" x 6"

      Materials: ABSplus Thermoplastic (Support plastic dissolved during printing)

ii.   **Fortus 250 3D Printer**
      Maximum Size: 10" x 10" x 12"

      Materials: ABSplus Thermoplastic (Support plastic dissolved during printing)

iii. **ZPrinter 450 3D Printer**
      Maximum Size: 8" x 10" x 8"

      Materials: Colored Plastic

3D Printing Materials

ABSplus Thermoplastic:

- Strong plastic

- Made from spaghetti like filament

- Many color options

- About 3 layers per 1mm

- 1mm minimum wall thickness

5. Detailed Design

5.1 Helmet Design

The purpose of this helmet is to hold the halo Coil above the ground and support it up and down and rotate with the help of linear actuator. The shape of the helmet is like a half circle, consisting of two parts which are the circle and the coil holder. And these two parts are made of plastic and will be fabricated through 3D printing method.

5.1.1 Stand System

The helmet support structure will stand behind the patient's seat and carry the weight of the coil to make sure there is no danger to the patient. There are two linear actuators in this system, aiming to stimulate different parts of brain by controlling these two pieces. By this means, the coil will up and down when the big main linear actuator moves up and down, and when the small side linear actuator moves up and down without moving the main actuator, the coil will rotate as desired.
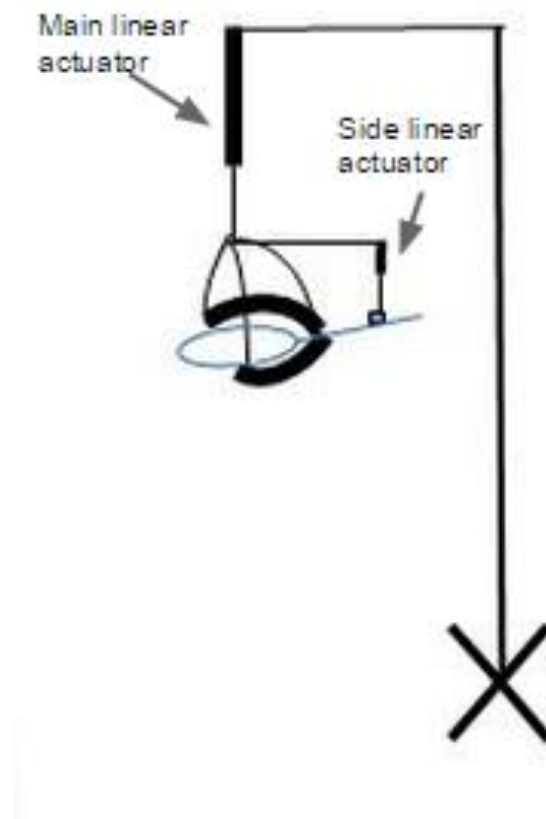

Figure 4: Whole view of the support structure

The figure shows the rotation system which is consist of a side linear actuator and the Halo coil.
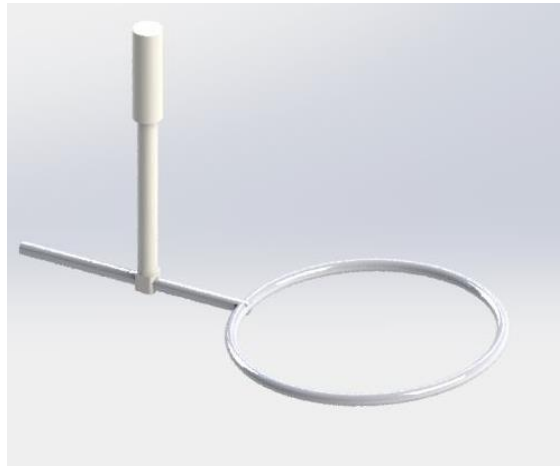

Figure 5: Halo Coil 3D Rotation System

5.1.2 Halo Coil Support System

We use the software Solidworks to model the plastic part and a printable file will be created into the 3D printer whenever it is finished. The plastic part is shaped with half circle surround with the Halo coil, it goes with the coil up and down.
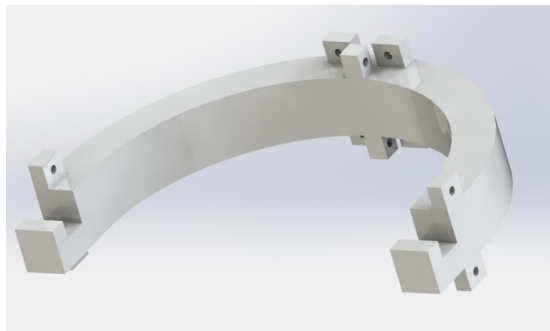

Figure 6: 3D Coil Support Structure

The coil holder can be rotated when some forces are pushed, in this case, when the small linear actuator above the cord moves without the main linear actuator moves, there are some vertical forces to the coil, leading the coil holder rotate.
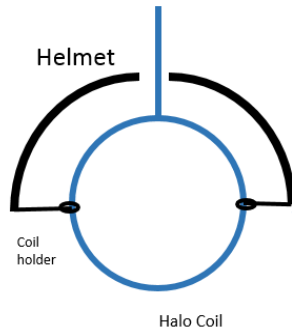
Figure 7: 2D Coil Support half circle Structure

Figure 8: Halo Coil Rotation Fixture

Here is the fabricated model of angular movement design

Figure 9: Real picture of helmet with rotational movement part

5.2 Control System

5.2.1 GUI Interface

1. The GUI is the interface used to control the system. It will show the position of the coil as well as the electric and magnetic field images for the position. These images will be color

coded using the color chart located at the left of the images. This is one of the most important part of our model, as the GUI will enable the user to move the coil around to stimulate different areas of the brain. The GUI will also be able to start the simulation by sending a pulse through a rs232 enabled port. The interface is where SEMCAD simulations are used. There will be two types of simulation pictures: E-field and H-field. Each type will have three images, a front view, left view and top view to show how the field changes in each direction.
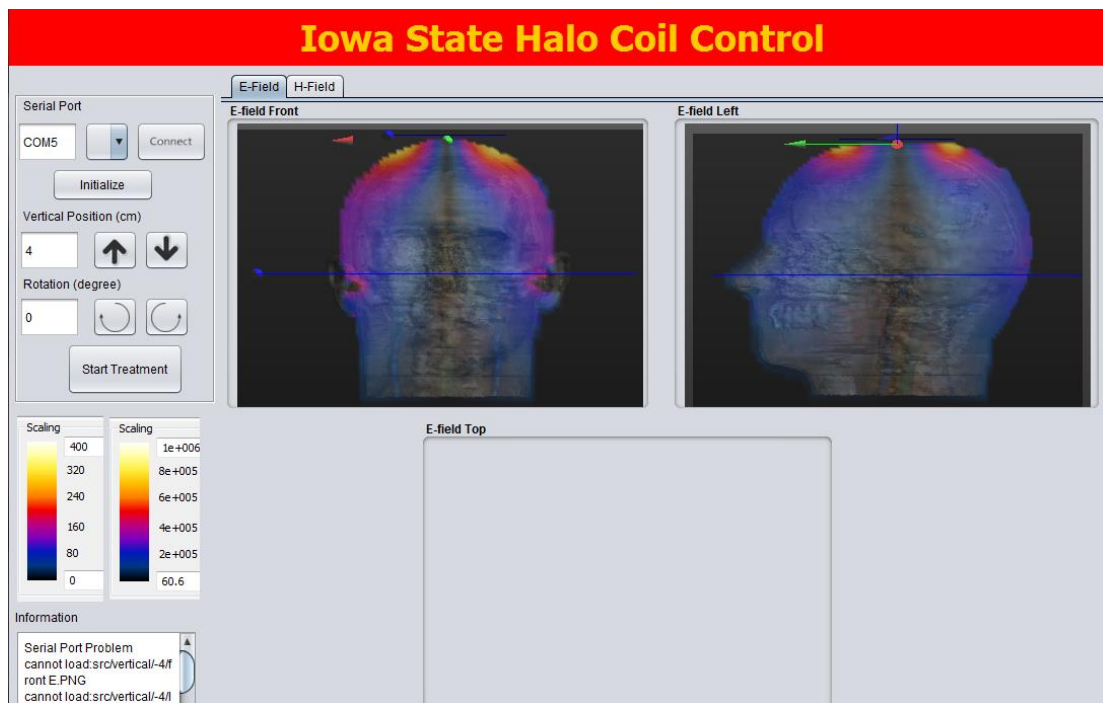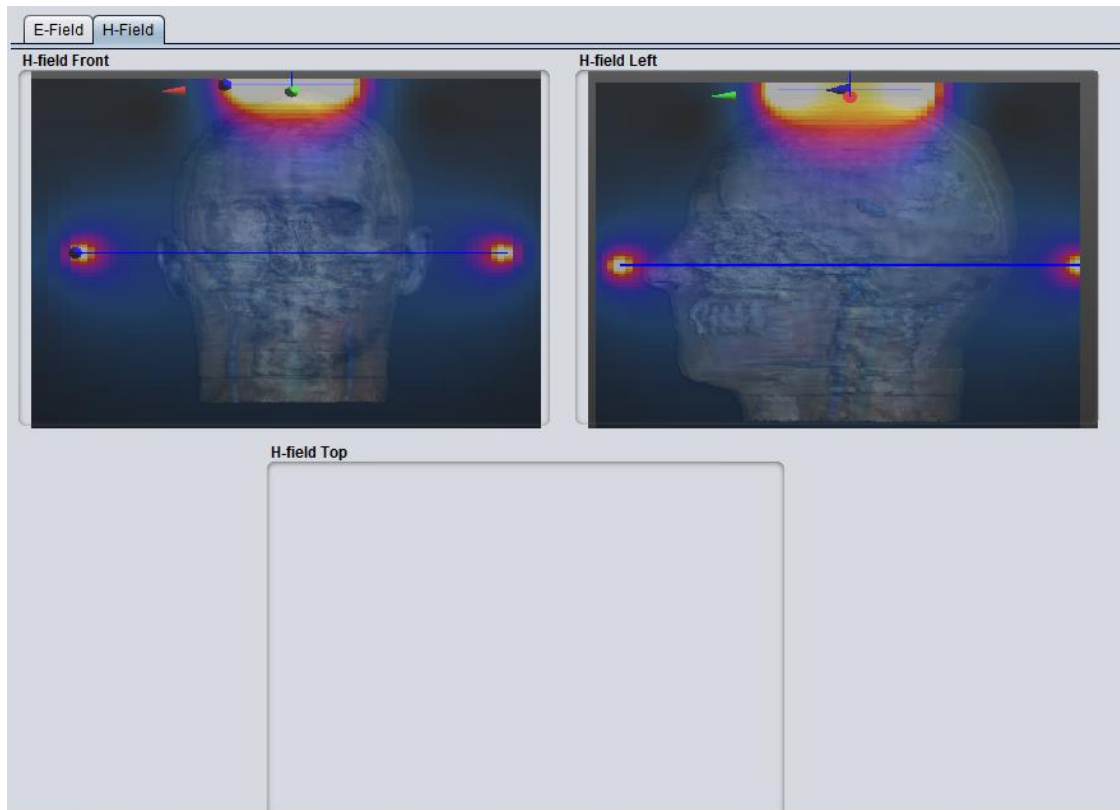

Figure 10: GUI Interface

Figure 11: GUI Interface: H-Field Pictures

2. The Arduino board requires a signal, which is given through a computer via a wireless environment. The arduino is programed using the Arduino program to make it easy to use. Its purpose is to control the movement of the coil and helmet based on signals sent from the GUI.

3. The Stimulation is started by sending a signal through the RS232 serial connector. This will be accomplished by connecting the GUI to a second port and sending the signal directly from the computer instead of using the arduino. All of this can be accomplished within the existing GUI and no other programs will be needed.

5.2.2 Wireless & Bluetooth Module

1. In order to replace the Arduino's USB interface (between the Arduino board and PC) to a wireless environment, we use two Radio Frequency (RF) module. One board is connected to the pc and the other one is connected to the Arduino board. We set same baud rate for both RF

module and Arduino board to get same channel to transmit and receive signals. In order to program the Arduino board wirelessly, we also need a shield called Wixel Shield connected between the Arduino and the Wixel module, which will make the uploading thing wirelessly.

Figure 12: Wireless module for Arduino board

2. Serial Bluetooth RS-232 Adapter

Figure 13: Bluetooth adapter

This Bluetooth serial adapter is used for serial cable replacement in our design between the stimulator and computer. It has a range up to 300 feet and can create a secure wireless communication link. We use this serial to Bluetooth adapter in pairs as a direct cable replacement, and the advantage of this setup is that it is easy and fast to setup even if your computer or serial device does not have built-in Bluetooth.

5.2.3 Powered by Outlet

The AC-DC converter used must be tested before it is connected to the design. This is done by connecting the AC side to a small transformer set up to mimic the output from an outlet. A voltage and current reading are then taken from the DC side. The voltage will have to be 12Vdc to power the linear actuators. The current emitted through the AC-DC converter needs to be small enough that it doesn't damage the parts. Once the converter has been tested on a transformer, it should be tested in the same fashion in an outlet. Only when it passes both parts of the test can it be attached to the halo coil motion circuit . Without this testing the parts used in the design could be ruined if they receive too much current or voltage.
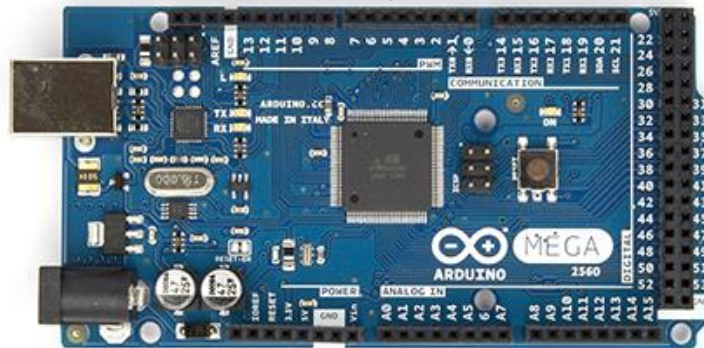
5.3 Hardware Specifications

Arduino Mega 2560

Figure 14: Top view of Arduino Mega 2560 board

The Arduino Mega 2560 is a microcontroller equipped with 54 digital digital pins, 16 analog pins and 4 serial ports. It has a 16MHz crystal oscillator and one USB connector. The USB -to-serial converter is a ATmega16U2.

For our project, this board will be used to communication between the computer and the linear actuators. The vertical and rotational actuators are connected to the arduino via a voltage shield and a dual H bridge respectively.

Haydon Hybrid Linear Actuator

Figure 15: Non-captive 12in side movement linear actuator

The side Linear Actuator we use for angular movement is a non-captive bipolar type step motor, which operates at 12V and 13W. The standard screw length is 12 inches and it travels 0.001 inch per step. This actuator is connected to the arduino using a dual H bridge that converts the PWM pulses into usable currents for each of the bearings inside. In our project, the coil moves vertically and rotates the halo coil in 5 degree increments.
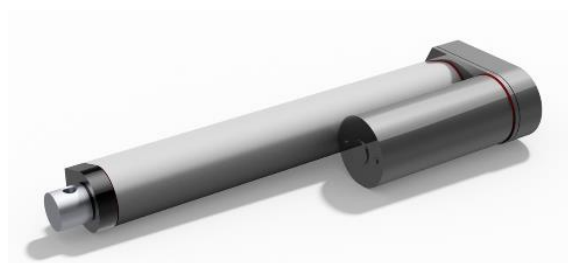
Firgelli Rod Actuator

Figure 16: Main vertical movement linear actuator

The main linear actuator is used since last year's group and it can load 35lb at 12V input, which is also suitable for our new design. We can control its movement in 1cm every step by sending command from GUI interface to Arduino board.

Power Supply

This AC-DC power adapter is used to supply two linear actuators and Bluetooth devices. After taking into consideration of all devices' load, which are 0.5A for wireless devices, 2A for stepper linear actuator and 4A for main linear actuator, we choose this 12V input and 8.5A current load adapter for our project.


Figure 17: Power supply for devices

6. Testing
6.1 Magnetic Field

The magnetic field is measured using a gauss meter connected to an automatic control system. This can be set to read the field in many different locations. The results need to be very accurate to ensure only a specific part of the brain is stimulated. These readings must be compared against the simulation results to verify that the structure isn't interfering with the fields.

6.2 Helmet & Coil Position

Testing the vertical movement of the helmet is done using centimeter ruler. The position of the structure can be compared to the information in the computer interface.

The testing of the halo coil rotation can be accomplished using a simple trigonometric function. The angle should be measured from the neutral zero position. This measurement can be directly compared to the information in the computer interface. In this figure, we can show that the X is the distance between rotation center and side linear actuator at zero degree, which is a constant 12-¼ inches, and if we want to move down to 5 degree, we can calculate Y as y1=x*tan(5 degree), thus the y is the distance the actuator should move in this lower direction; If we want to move down to 5 degree more, which is 10 degree in total from zero degree, we can calculate y2= x* tan (10 degree), and in this time, we give computer a command
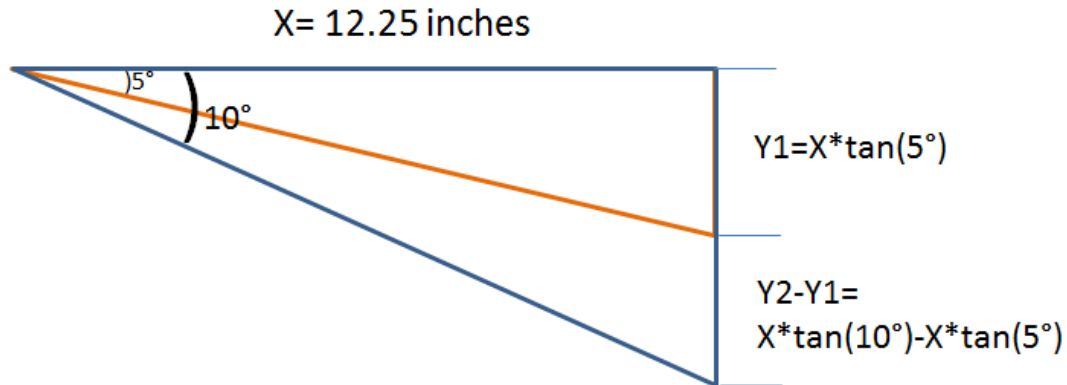
of moving distance y2-y1 downward to make the coil rotate 10 degree downward.

Fig 18: Method for calculating the rotation angle

6.3 Temperature

The actual temperature of the coil will be measured using thermometer. These thermometers are already integrated into the coil itself. In order to ensure safe functionality the temperature must never exceed 37 degrees Celsius otherwise the coil will heat up and start melting the plastic cover.

Appendix I   Operation Manual

Computer Requirement: Must have Java Runtime Environment 1.7 or higher installed.

JRE can be downloaded from the following website: https://www.java.com/en/download/

Setup:

1) Download "SeniorDesign.jar" to your computer and save it.
2) Open the program with Java Runtime Environment.
    a) Right Click on the icon and select "open with"
    b) choose the defalut program by browsing the computer.
    c) Navigate to C:\Program Files\Java\jre7\bin
    d) Select the Javaw.exe program.
3) Double click on the "SeniorDesign.jar" icon.

Operation Instructions:

1) Select the com port connected to the wixel pair in the first drop down box.
2) Click the connect button located next to the drop down box to link the wixel pair to the computer.
3) Select the initialize button to set the halo coil to the resting position of 0 degrees rotation and 2 degrees vertically.
4) Position the halo coil vertically by selecting the up or down arrow or enter a value into the text box located below the "Vertical Position" text.
5) Position the halo coil rotationally by selecting the left or right rotation buttons located under the "Rotation" text. This can also be done by typing a value into the corresponding text box.
6) The halo coil will move automatically when data is sent.
7) To start the stimulation, first select the proper com port from the drop down box under the "stimulator Port" text.
8) Select the "Start Simulation" button to send a pulse to the stimulator. Once it is complete the program will automatically reconnect to the wixel port.

9) The E field images for each vertical and rotational position can be seen in the E-field tab while the corresponding magnetic field images can be seen in the H-field tab. These tabs are located at the top of the program.

10) The scaling of the images are located right below the control panel The E field is located on the right and the magnetic field scaling is located on the right side.

11) Any errors that occur will be displayed in the information panel in the bottom left of the program. This will also give information on the vertical and rotational positions whenever data is sent to the actuators.
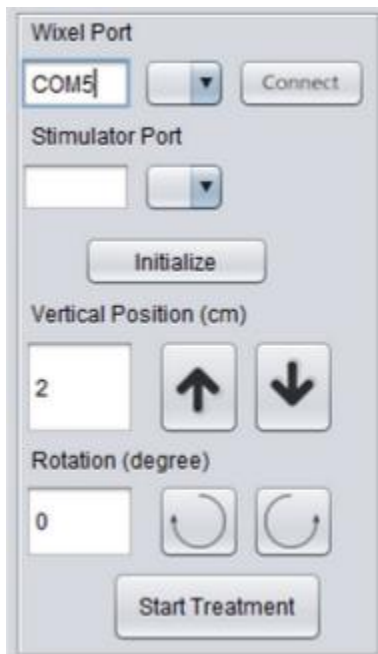
Appendix II   Alternative Design

1. 3D Model Change

Last group's design (Fig.1) is use two brackets which are holding two servo motors. In our design, we stop using two servo motors since they cannot hold the weight of the coil, and their connectors to attach the plastic helmet to the frame is not strong enough. So in our new design, we aim to add a side linear actuator to control the movement of the coil, which there are three bearing points for holding the coil firmly. In this case we redesign the structure to Fig. 2, we change the diameter of the half circle helmet to fit our new idea and add two extrude parts for our coil holders. We also make the connecting parts much more strong.
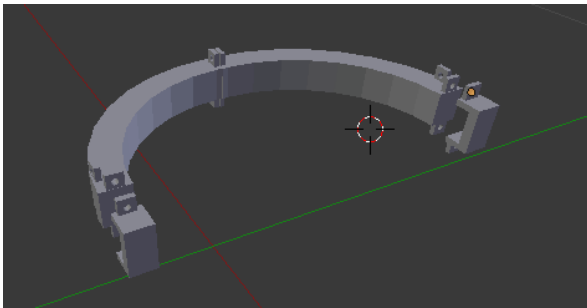

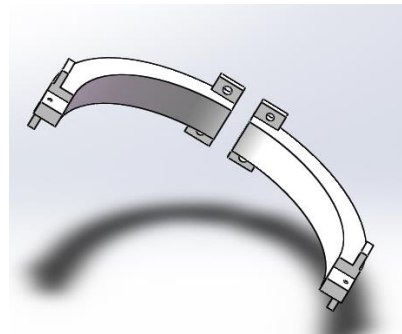Fig.1 Cite from last group's design

Fig.2 First design of our project

After thinking about the angular movement carefully, we find that the coil holder may still move in the horizontal direction when the coil rotates, so we modify the model to Fig.3, which will hold the coil older just in that slot and no other room to vibrate and move during the rotation movement of the coil.
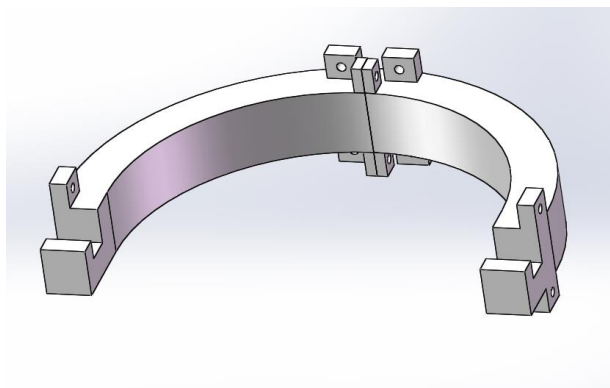

Fig.3 Modified design of our project
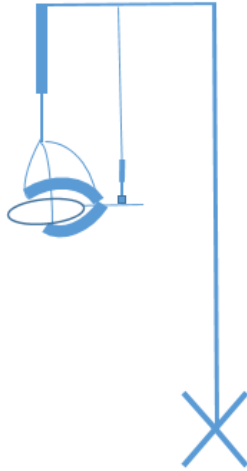
2. Standing System Change

Fig. 4 Initial design for holding side actuator   Fig.5 Changed Design

At first, we aim to hold the side linear actuator simply to the top of the standing frame to make it straight forward, however, we have to control both the side linear actuator and the main linear actuator at the same time to make the coil moves vertically, which is much more complex and hard to handle during the control steps. In order to make the system function like only move the main actuator to control the vertical movement and the angular movement only controlled by the side linear actuator, we change our design to Fig.5, which the main linear actuator can control both the helmet and the side linear actuator.

Appendix III   Other Consideration

Limitations/Risks

1. Simulation software.

In this project, simulation and design software will be heavily used. They are used to create the advanced tests used throughout the simulation process. The values calculated in these programs directly influence the length of stimulation. If these simulations are off in any way the doctors will run the risk of injuring the patient.

2. Achieve accuracy requirement

The movement of the coil and the helmet rely solely on the linear actuators. Finding an actuator of the right size with high resolution is essential for the rotation. If the linear actuator used isn't reliable in its movements it could cause the entire electromagnetic field to become distorted. If the actuator used for the vertical movements isn't consistent in the distance traveled as it extends the top coil could be located the wrong distance from the patients head which would weaken the magnetic field on the human skull. These could potentially cause the field to focus in the wrong part of the brain.