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

Design Document

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MAY 2015 GROUP 26

Iowa State University

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2. Project Overview

2.1 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.

2.2 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 design the machine, we will carefully calibrate the functional accuracy to make the result as accurate as possible and meets the requirement.

2.3 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 rotational linear actuator to hold the handle of the coil

iii. New structure to link the new rotational actuator to the main vertical actuator so that they can move together.

3. Requirements

3.1 Functional Requirements

Generate 150Volts per meter in target area of the brain.

Helmet 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

3.2 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 UI is supposed to be written in a way that function can be easily added or removed.

4. System Description

4.1 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. The new design will be more streamlined in its design and operation.

The placement of the halo coil system wasn't very precise. Not only was the movement sporadic, the measurements of the physical parts didn't match up with the reading on the user interface.

By using the existing design, flaws in the rotation and user interface were singled out to be the problem. Centralizing the rotation and modifying the helmet design allows the halo coil better movement and accuracy around the head.

4.2 Concept Sketches

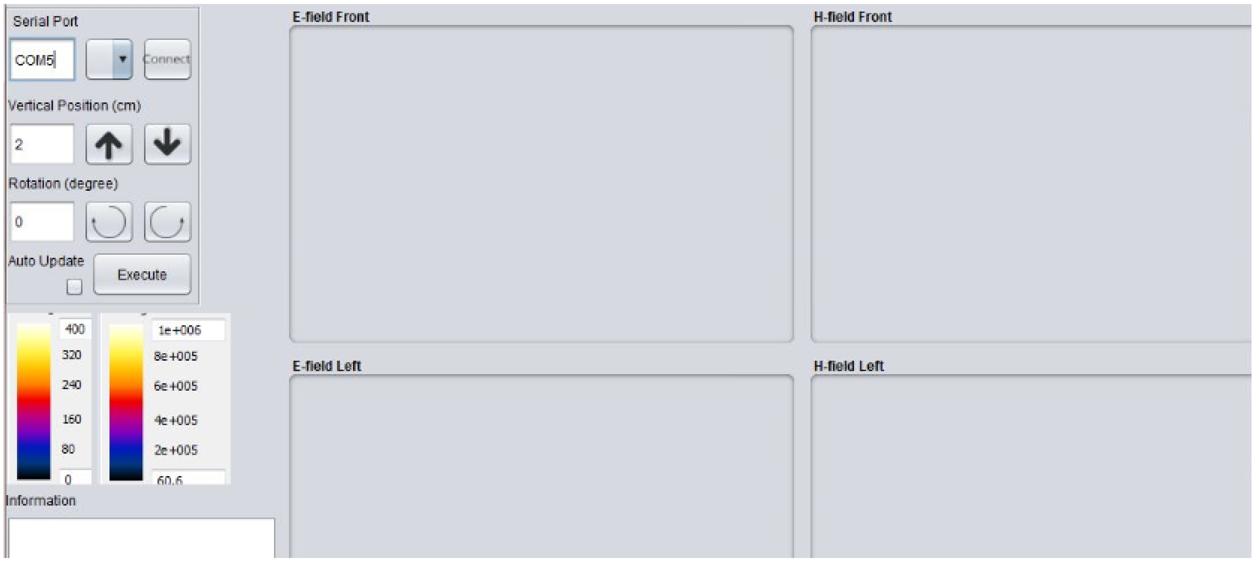

Figure 1: User Interface Concept Sketch

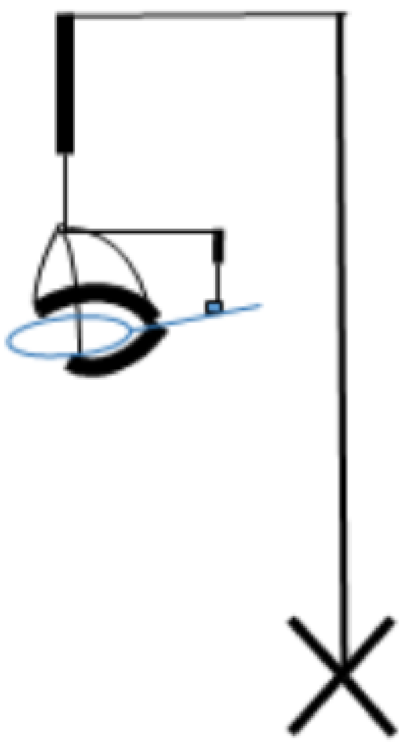

Figure 2: Coil Holder Concept Sketch

4.3 Block Diagrams

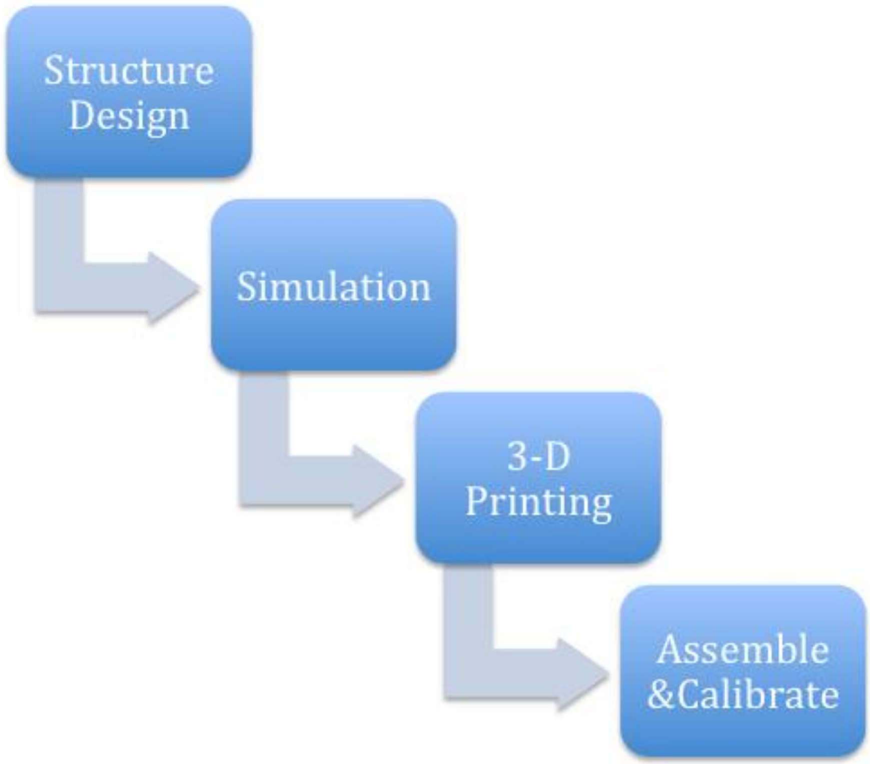

Figure 3: Block Diagram

4.4 Component Specifications

Coil Dimensions

Single Coil

- Average diameter :9 cm
- Number of turns: 14

Double Coil

- Inner diameter: 32mm
- Outer diameter: 48 mm
- Number of turns: 9 turns
- Space between turns: 1 mm
- Turn width: 1 mm

- Winding dimension: 1 mm*5 mm

Halo Coil

- Inner diameter: 277 mm
- Outer diameter: 299 mm
- Number of turns: 5 turns
- Space between turns: 1 mm
- Turn width: 6 mm
- Winding dimension: 1 mm*5 mm

Helmet dimension

Helmet

- Half circle average diameter: 334mm
- Coil holder diameter: 22mm

Stand system

- Number of linear actuator: 2

5. Design Process

5.1 Simulations

5.1.1 Electric and Magnetic

Introduction-

We use the SEMCAD simulation software 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 at each position of the halo coil. By slicing the simulation results along the x, y and z axis, the user can easily formulate an idea of how the field is propagating.

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 90mm 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 to identify the area where maximum field is located.

Results-

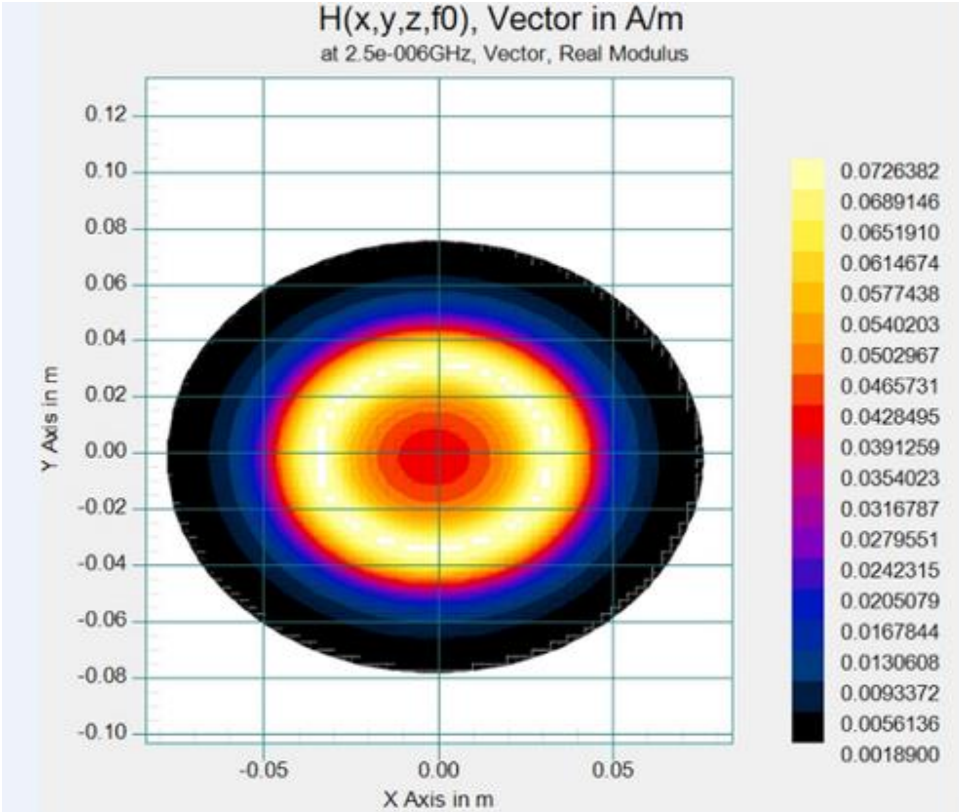

Figure 4: Magnetic Field along Z axis

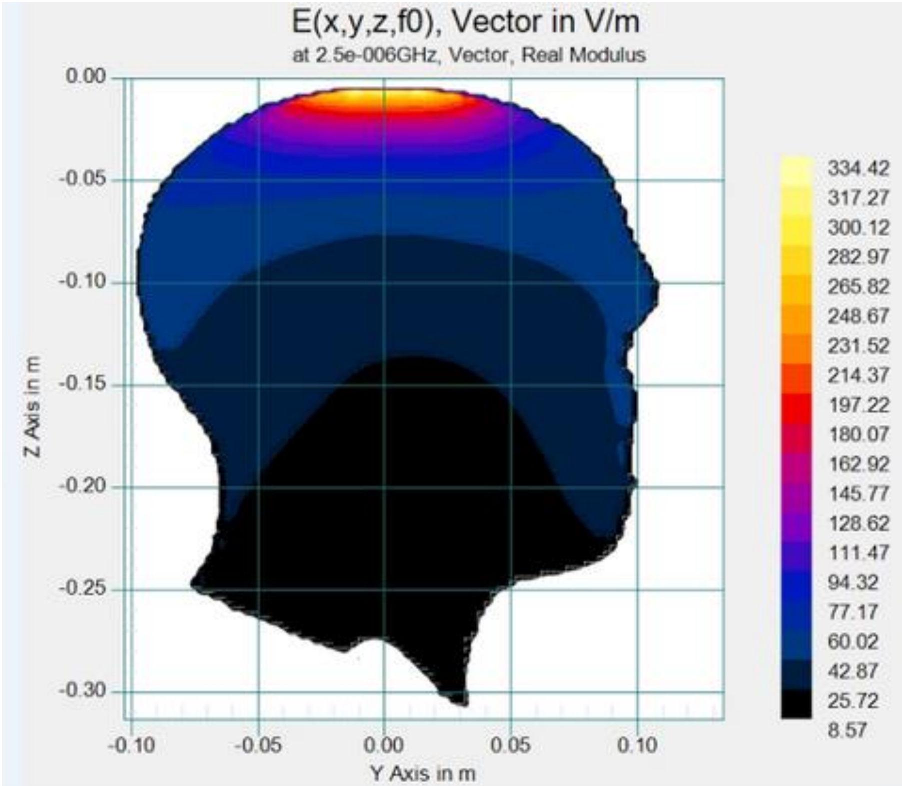

Figure 5: Electric Field along X axis

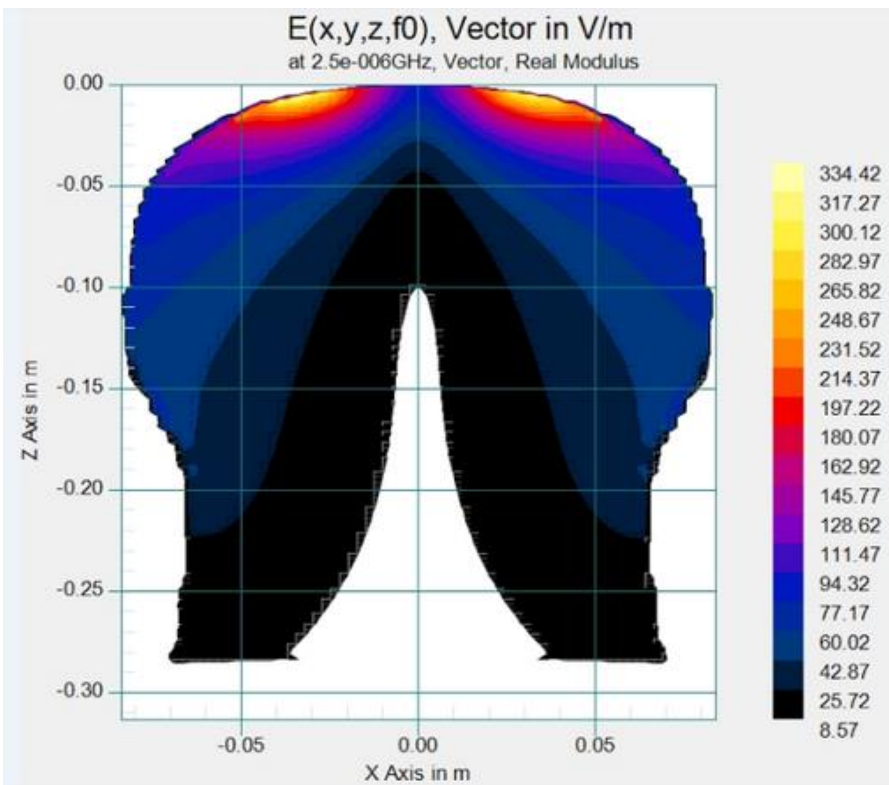

Figure 6: Electric Field along Y Axis

5.1.2 Electromagnetic Heat

Introduction-

These simulations are very important as the coil should not get very hot as it can cause discomfort and much worse. The temperature should not exceed 37 degrees Celsius which is the human body temperature. The simulations are done in order to find the maximum time our coil can be used before it reaches this temperature and the treatment has to be stopped.

Procedure-

We use COMSOL for heat simulations. In COMSOL we use joules heating model for electromagnetic heating. Once we have created our coils and placed them correctly, the frequency of the sinusoidal wave is set to 2.5 KHz and magnitude is 5000 A. We then run the simulations and check till the temperature reaches the 37 degree mark.

Results-

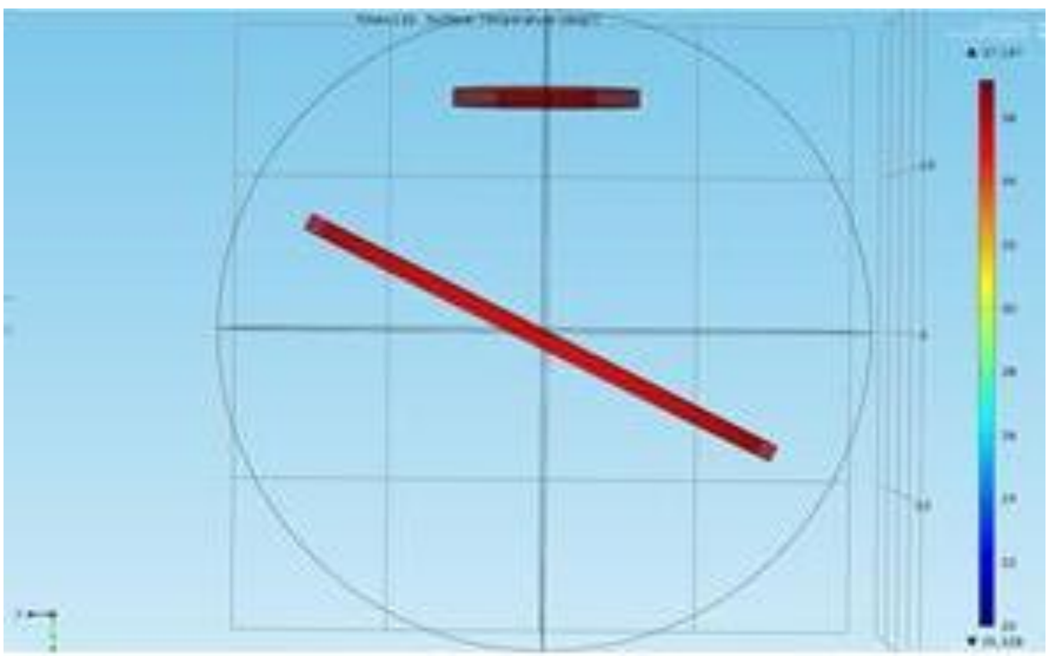

Figure 7: Heat Simulation 30 degree Coil Rotation

5.1.3 Magnetic Force

Introduction-

We need to simulate for the force as well because the two coils can apply some force on the whole system. We are dealing with very sensitive instruments and designs and need to ensure precision. The force simulations are done so we know how far the coils must be placed from one another so the forces generated do not impact the helmet during the treatment as it could cause major issues. Also stability needs to be ensured, which is why all acting forces must be taken into account.

Procedure-

COMSOL is used for these simulations as well. Electromagnetic Force is chosen this time. Using the same coil design as earlier, we move the coils to find the distance at which the acting force is at its minimum.

Results-

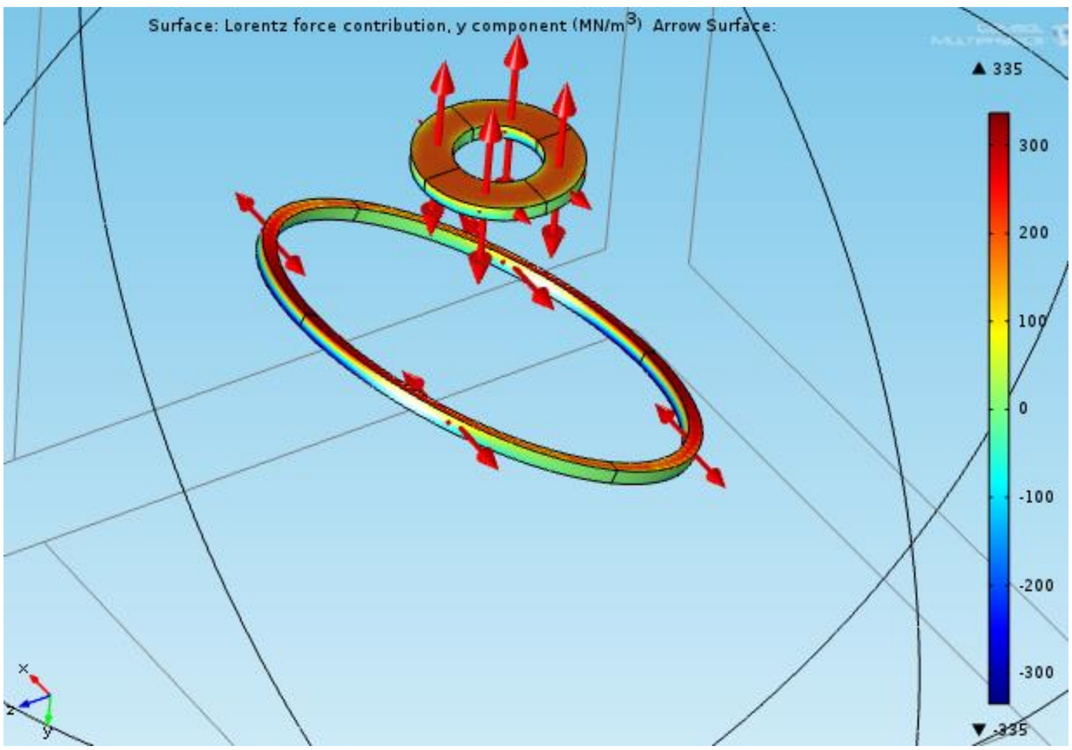

Figure 8: Force Simulation 30 degree Coil Rotation

5.2 Materials

3D Printing Locations

a. **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

b. **Prototyping & Fabrication Service Center (Iowa State University Howe Hall 1380)**
   i. **Alaris 30U**
      Maximum Size: 7.12” x 11.57” x 5.9”

      Materials: Colored (black, white or grey) hard Plastic

   ii. **Connex 260**
      Maximum Size: 10.2” x 10.2” x 7.9”

      Materials: Colored (black, white, grey or clear) hard Plastic

3D Printing Materials

NYLON: (Polyamide)

- Also called White, strong & flexible / Durable plastic / White plastic
- Strong and flexible plastic
- 1mm minimum wall thickness
- Naturally white, but you can get it colored
- About 10 layers per 1mm
- Made from powder

- Alumide = Polyamide + Aluminum
- Interlocking, moving parts possible (Chain)

ABSplus Thermoplastic:

- Strong plastic
- Made from spaghetti like filament
- Many color options
- About 3 layers per 1mm
- 1mm minimum wall thickness

6. Detailed Design

6.1 Helmet Design

The purpose of this helmet is to hold the Halo Coil above the ground while the system moves vertically. It also facilitates the rotational movement by holding the pivot point connectors. The shape of the helmet is a semi-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.

6.1.1 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.

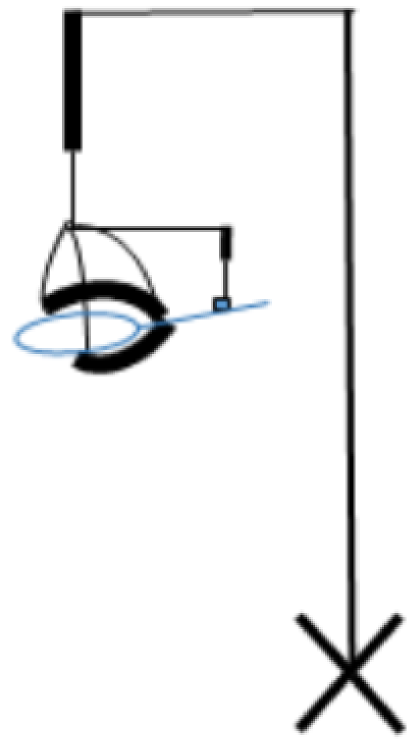

Figure 9: Halo Coil 3D Rotation System

The figure below shows the rotation system which is consist of a side linear actuator and the Halo coil. When the actuator retracts, the coil will rotate down.

Figure 10: Halo Coil 3D Rotation System

6.1.2 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.

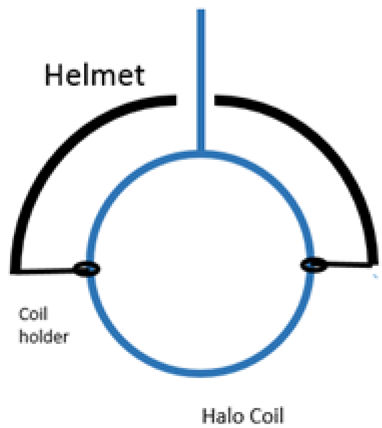

Figure 11: Top down Coil Support Structure

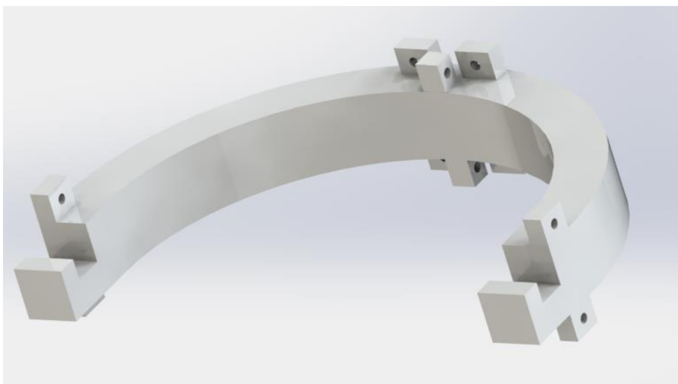

Figure 12: 3D Coil Support half Structure

The pivot fixture is a two part item. The top rotates separately from the bottom in specific intervals. These intervals will give extra support to the coil while the treatment is in progress allowing the rotational actuator to be shut off. The space between the two parts will have to be increased to allow for slightly easier motion. Otherwise the calibration of the actuator may be off.

Figure 13: Halo Coil Pivot Fixture

6.2 Control System

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.

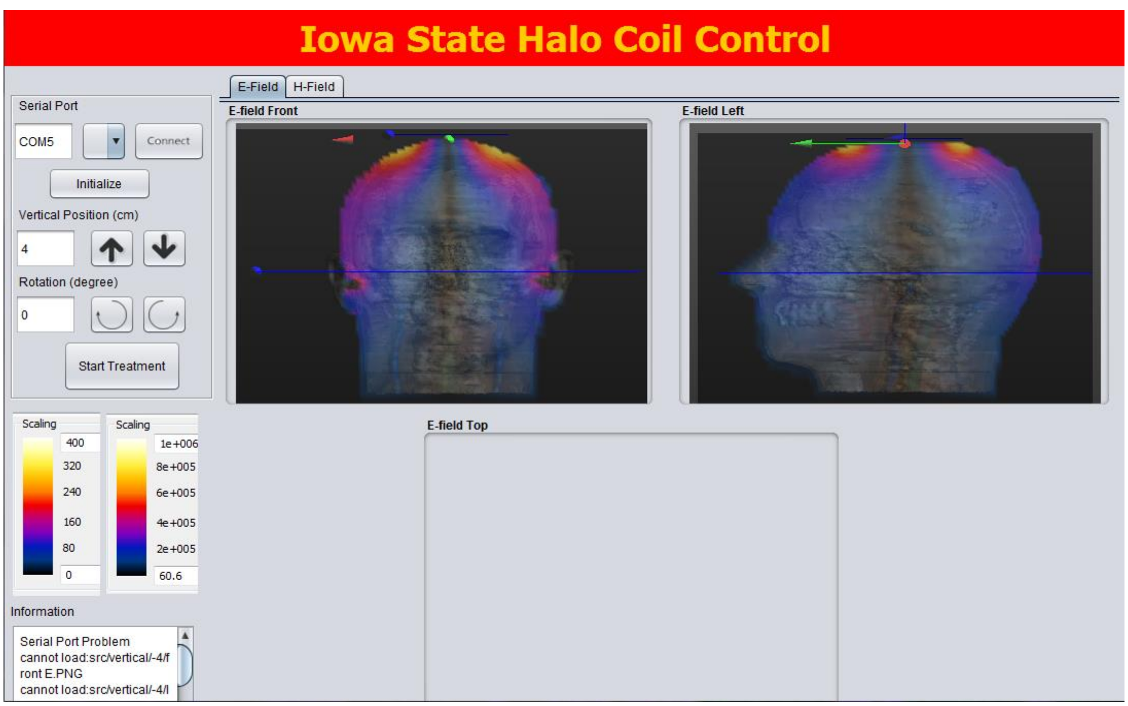

Figure 14: GUI Interface

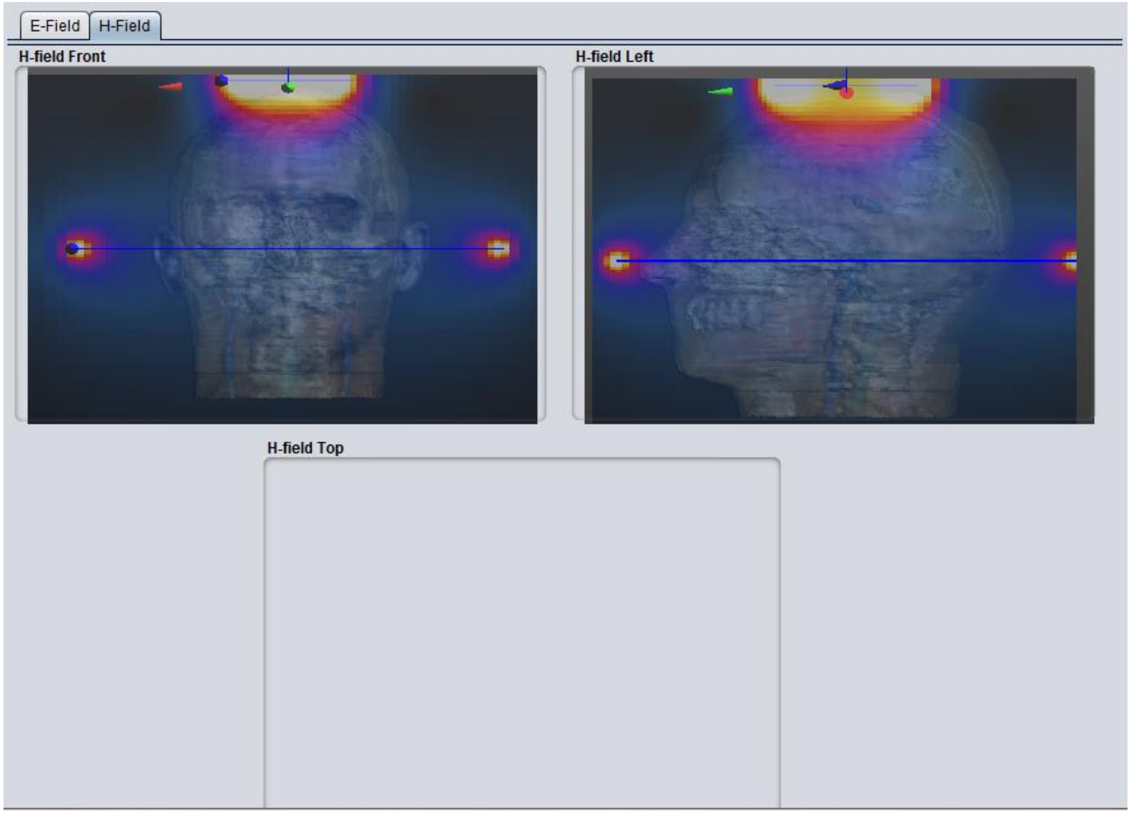

Figure 15: GUI Interface: H-Field Pictures

2. The Arduino board requires a signal, which is given through a computer via a USB cable. 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.

6.3 Hardware Specifications

Arduino Mega 2560

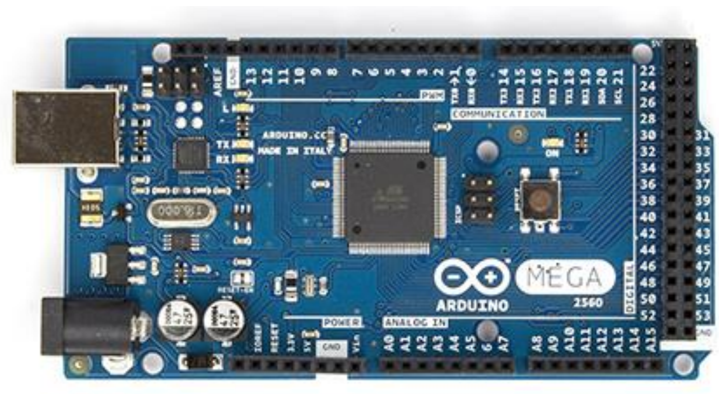

Figure 16: Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller equipped with 54 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 an ATmega16U2.

For our project, this board will be used to communication between the computer and the linear actuators. The Arduino will get two separate inputs, a 12Vdc signal and a signal from the computer. By connecting the linear actuators to their power source through the Arduino they can be accurately positioned by controlling the power source.

Haydon Hybrid Linear Actuator

Figure 17: Hybrid Linear Actuator

The hybrid linear actuator is a product that can apply a force of 200 pounds. It is built to order with varying specifications. The item used in our design is 57J41-12-XXX. It is a 12Vdc, .9

degree non-captive bipolar actuator. The screw is 12 inches long with a resolution of .0254mm per turn.

This actuator will be used to accurately rotate the coil and maintain that position without overheating. It will be able to move the halo coil in one degree increments with little to no reasonable error.

Firgelli Rod Actuator

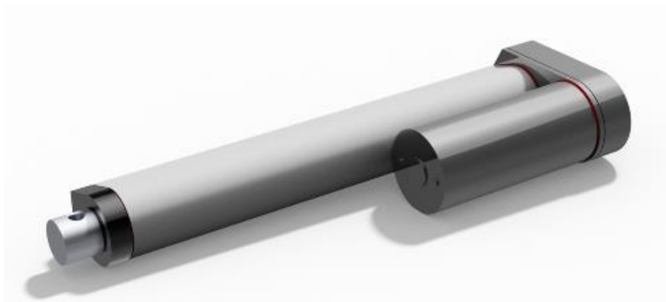

Figure 18: Rod Actuator

The Rod actuator being used for linear motion is a Firgelli Light Duty Rod Actuator. It has a force of 35 lbs and a stroke length of 12 inches. It runs at 12Vdc with a current draw of up to 5A. It can withstand a static force of 70 lbs.

This linear actuator will be used to move the entire system vertically. It doesn't have to be nearly as accurate as the rotational actuator because its placement doesn't directly affect the treatment. It is just there to bring the helmet to a comfortable position for the patient. It moves in one centimeter increments.

7. Testing

Three main tests will be performed on the finished design. These will test the placement of the coil as well as its performance. All of the results will be compared to the simulated results and the user interface. If all three pass than the design will meet the basic requirements of the project.

7.1 Magnetic Field

The magnetic field is measured using a guassmeter 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 images used in the GUI are accurate.

7.2 Helmet & Coil Position

Testing the vertical movement of the helmet is done using a ruler with centimeter markings. 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 protractor. The angle should be measured from the neutral zero position. This measurement can be directly compared to the information in the computer interface.

7.3 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.

8. Implementation Challenges

The most difficult part of this design is going to be achieving the required accuracy for the linear actuators. Higher accuracy actuators often cost more money. Most of the high resolution actuators only have a 1 inch stroke. Although an appropriate actuator has been found, the length of the stroke may cause the actuator to be unstable during rotation. The structural stand design will have to compensate for this extra movement but it may be difficult given the materials and money available.

9. Conclusion

The final project will be a beta system capable of market use once the halo coil technology has finished all of its testing. Because the technology is still relatively new, many things may change when the coil begins human studies. The design built may actually be used for that phase of testing and be cleared for distribution to hospitals all over the world.

10. Sources

Arduino Specification Sheet

http://arduino.cc/en/Main/ArduinoBoardMega2560

Light Duty Rod Actuator Specification Sheet

http://www.firgelliauto.com/products/light-duty-rod-actuator

Non-captive Hybrid Linear Actuator Specification Sheet

http://www.haydonkerk.com/LinearActuatorProducts/StepperMotorLinearActuators/LinearActuatorsHybrid/Size23LinearActuator/tabid/82/Default.aspx#Stepper_Motor_Linear_Actuator_noncaptive