May 2014 Group 9
Variable Coil Helmet System for Transcanial Magnetic Stimulation (TMS)

Final Report

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1 Project Overview

1.1 Introduction

Transcranial Magnetic Stimulation (TMS) is a medical procedure intended to treat various neurological disorders. These disorders include post-traumatic stress disorder, depression, and Parkinson’s disease. The procedure involves stimulating different areas of the brain with a magnetic field. The magnetic field then induces an electric field within that area.

Prior to the halo coil research groups had difficulty stimulating the deeper regions of the brain. The halo coil system consists of two coils. The smaller stationary coil rests on top of the patient’s head while the larger halo coil circles the patient’s head. In this way the two fields combine and interact in different ways depending on the position of the halo coil.

1.2 Purpose

The purpose of the project is to design a test fixture for the halo coil. The test fixture, or helmet, must move the halo coil so that the system generates an electric field within a specific portion of the patient’s brain. This will require the helmet to be capable of moving the halo coil vertically as well as tilting the halo coil.

1.3 Deliverables

A test fixture for the halo coil system. This test fixture will include:

- A structure to hold the coils in place
- Motors to position the halo coil
- A program that takes into account simulation data and user input to correctly place the coil

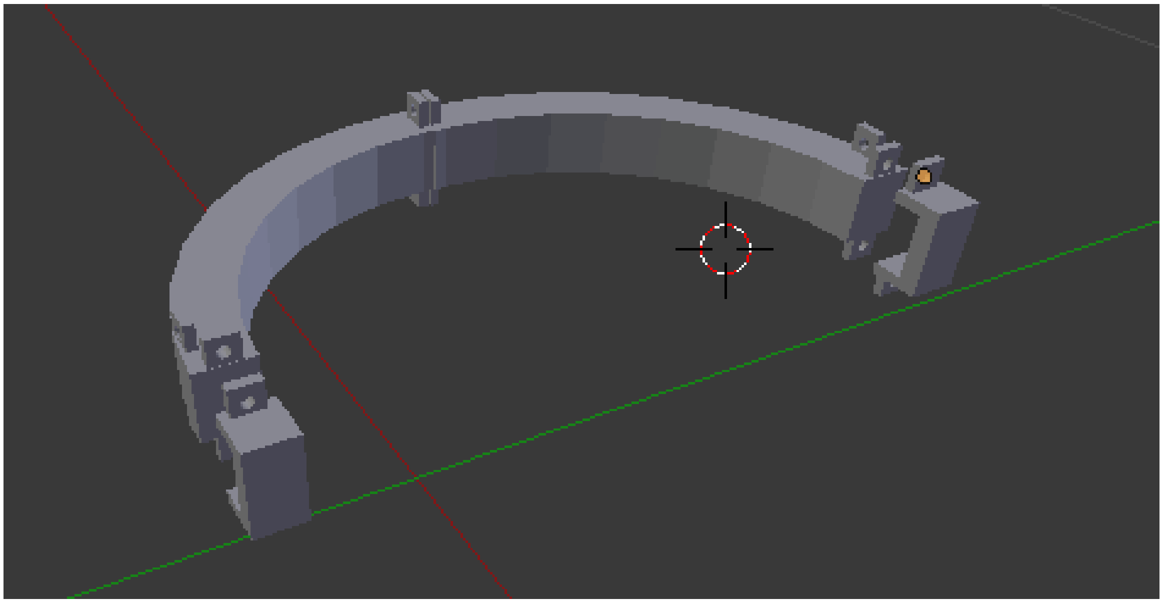


Figure 1: 3D model of the rotational positioner

2 Requirements

2.1 Functional Requirements

Description	Inputs	Behavior	Outputs
Generate a 2 T magnetic field at the desired location	Command from PC interface	Generate a 2 T magnetic field at the desired location	The magnetic field should display on the PC interface.
Place the helmet easily via machine	Command from the PC interface	Move the helmet to the required place	The movement of the helmet and its final position should display on the PC interface

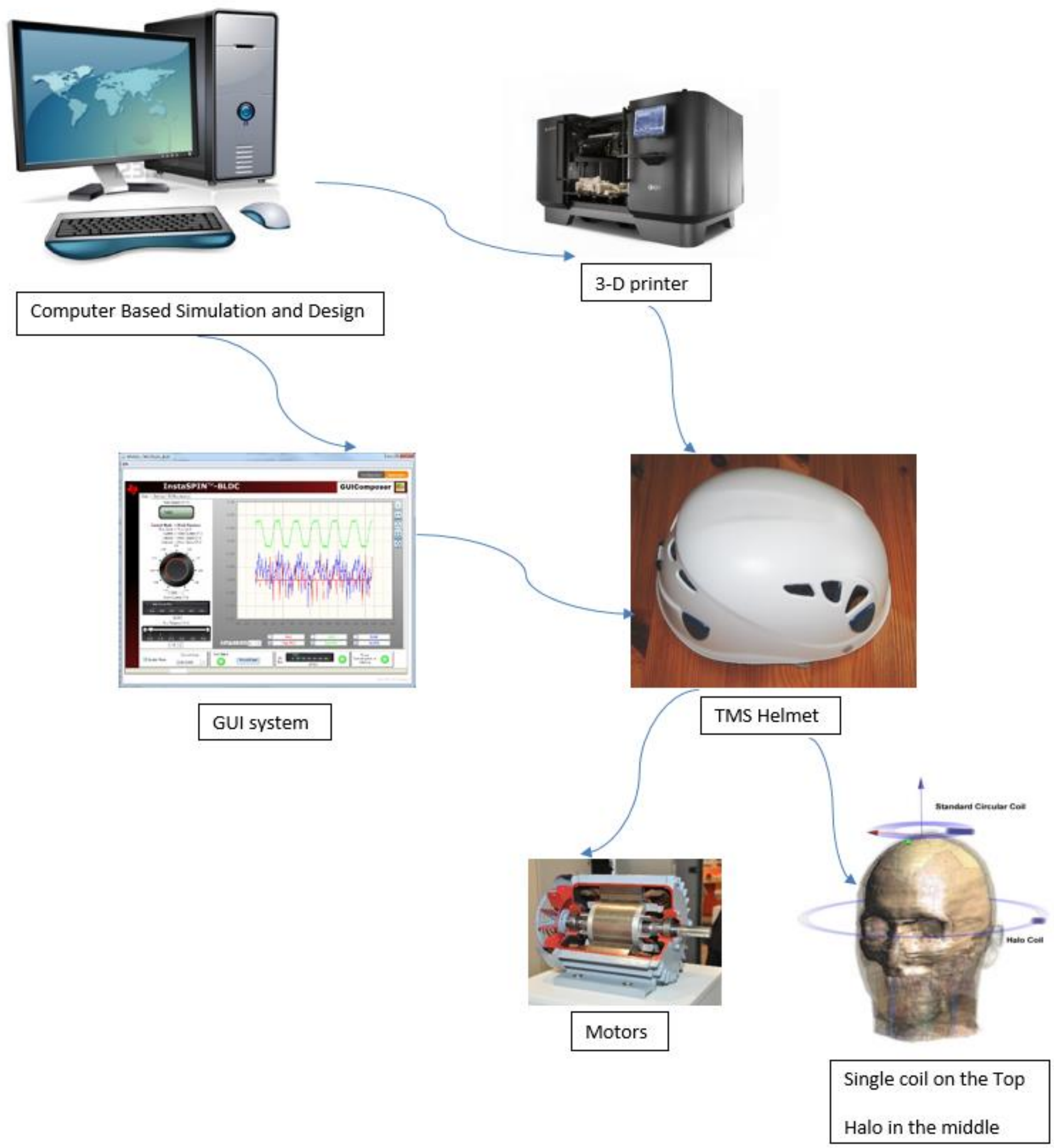
2.2 Non-Functional Requirements

- **Accuracy** - Must provide consistent results
- **Comfort** - Must account for the patient's comfort
- **Variability** - Must be capable of fitting many different head sizes and different heights
- **Extensibility** - Source code for UI should be written in a way that functions can

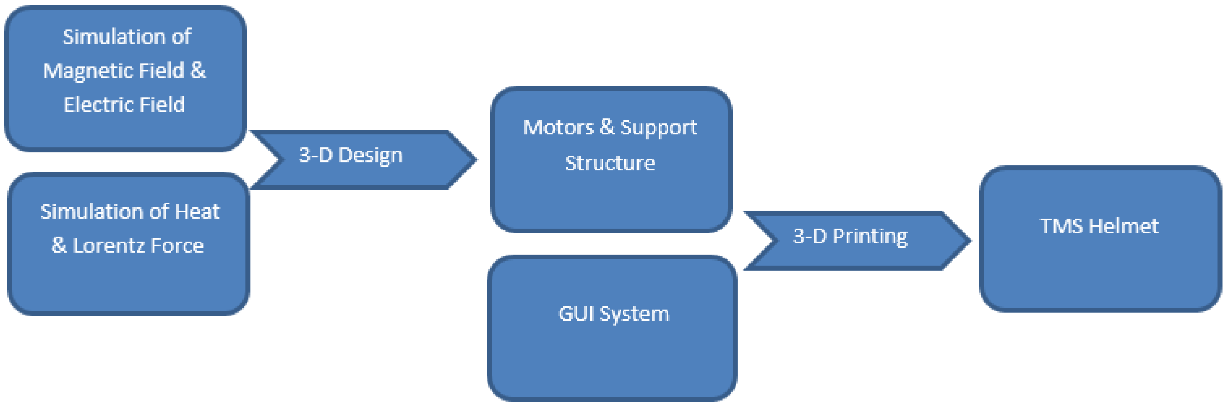
be easily added or deleted

3 System Description

3.1 System Concept Sketch



3.2 System Block Diagram



3.3 Components

3.3.1 Coil specifications

Double Coil

- Inner diameter: 32mm
- Outer diameter: 48 mm
- 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
- 5 turns
- Space between turns: 1 mm
- Turn width: 6 mm
- Winding dimension: 1 mm*5 mm

3.3.2 Helmet specifications

Support Structure

- Height: 2 m
- Arm length: 40 cm

Half Halo

- Average diameter: 33.9 cm

Vertical Positioner

- Load: 10 lbs.

4 Design Process

4.1 Simulation

4.1.1 Electric and Magnetic Field Simulation

i. Introduction

The first part of the project was to prove the principal behind the operation of the halo coil system. A simulation of the magnetic and electric fields using the program SEMCAD must show variation in the fields as the position of the halo coil changes.

ii. Methods

The first step is to build the model of a simple head and a halo coil.

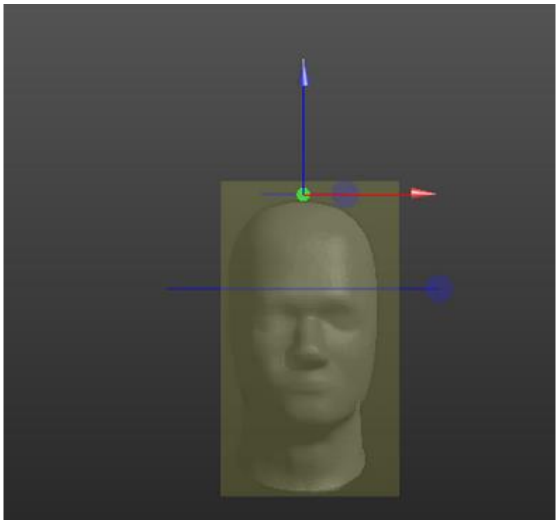


Figure 2: The simple head model

The top coil is the single coil and the lower coil is the halo coil. The diameter of the single coil is 90 mm and it has 14 turns. The diameter of the halo coil is 290 mm and it has 5 turns. The distance between the single coil and the top of the head is 5 mm. The distance between the single coil and the halo coil is 10 cm. During the simulation process, the halo coil rotates upward 30 degrees and downward 30 degrees in increments of 5 degrees, generating 12 data points. The halo coil also moves up 5 cm and down 5 cm with a resolution of 1 cm.

iii. Results

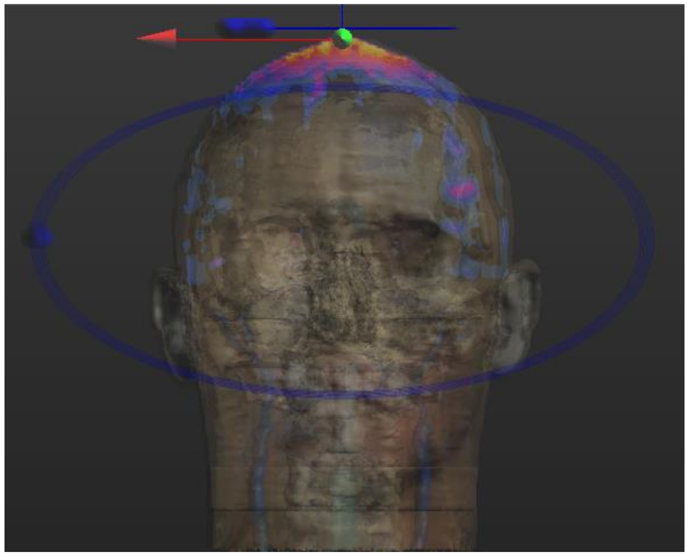


Figure 3: Electric field at the back of the head with the halo coil positioned at 30°

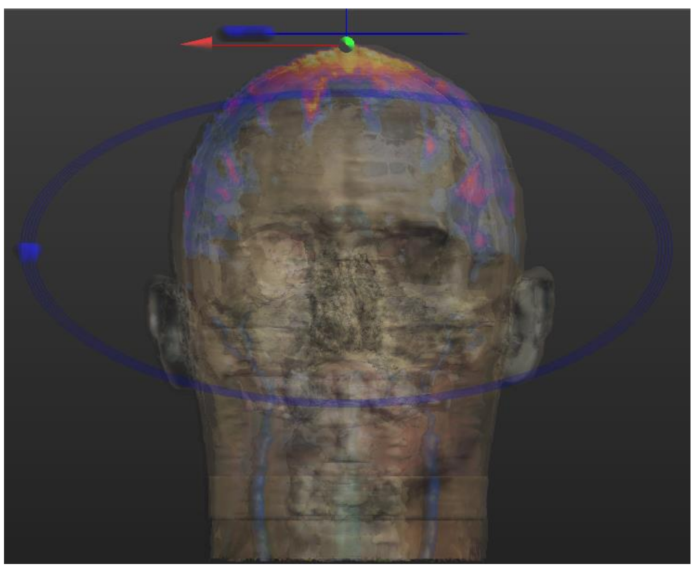


Figure 4: Electric field at the back of the head with the halo coil positioned at -30°

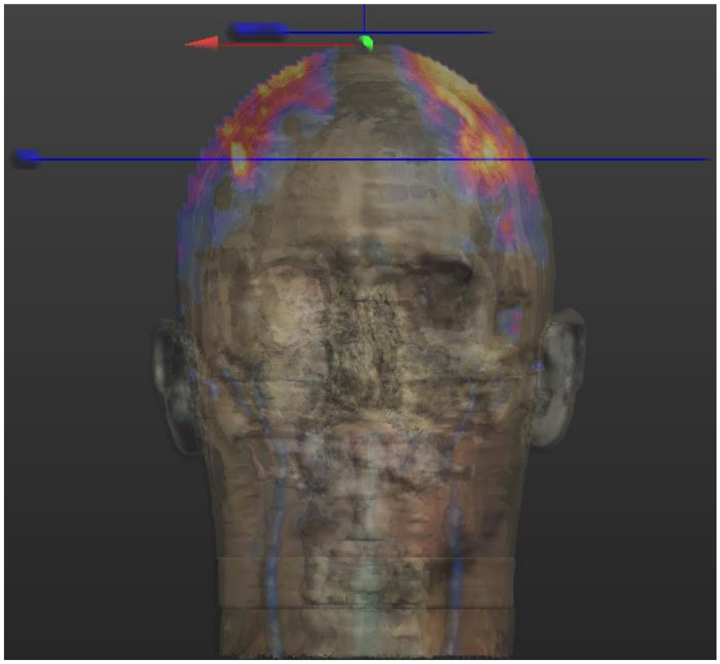


Figure 5: Electric field at the back of the head with the halo coil at the highest position

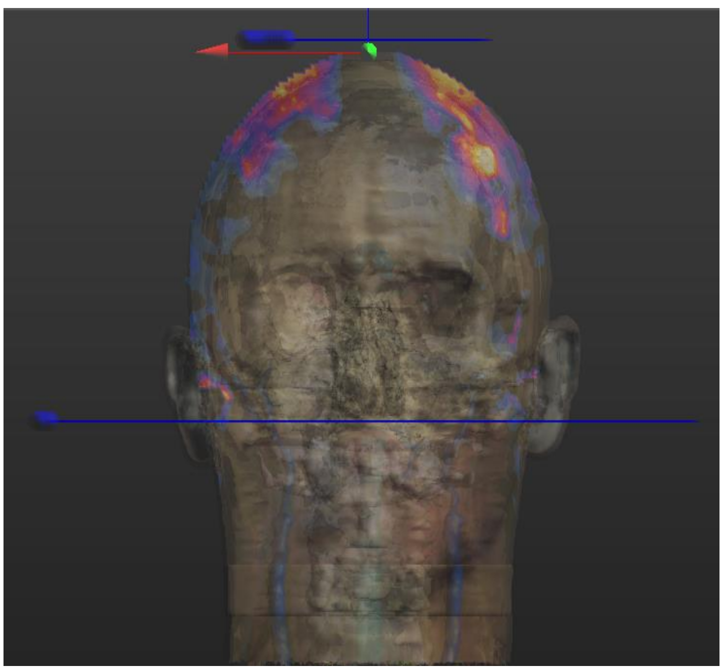


Figure 6: Electric field at the back of the head with the halo coil at the lowest position

The figures show a variation in the electric field as the halo coil moves to different positions, proving to theory of operation of the halo coil system.

4.1.2 Electromagnetic Heat Simulation

i. Introduction

Due to the heat standards of human medical treatment, the surface temperature of the coils should not exceed 37°C. Because of the high current, both of the coils heat up quickly. In order to comply with the medical standards, a COMSOL Multiphysics electromagnetic heat simulation determined the length of time a TMS treatment may last.

ii. Methods

The first step of the simulation process is to build a model of the coils.

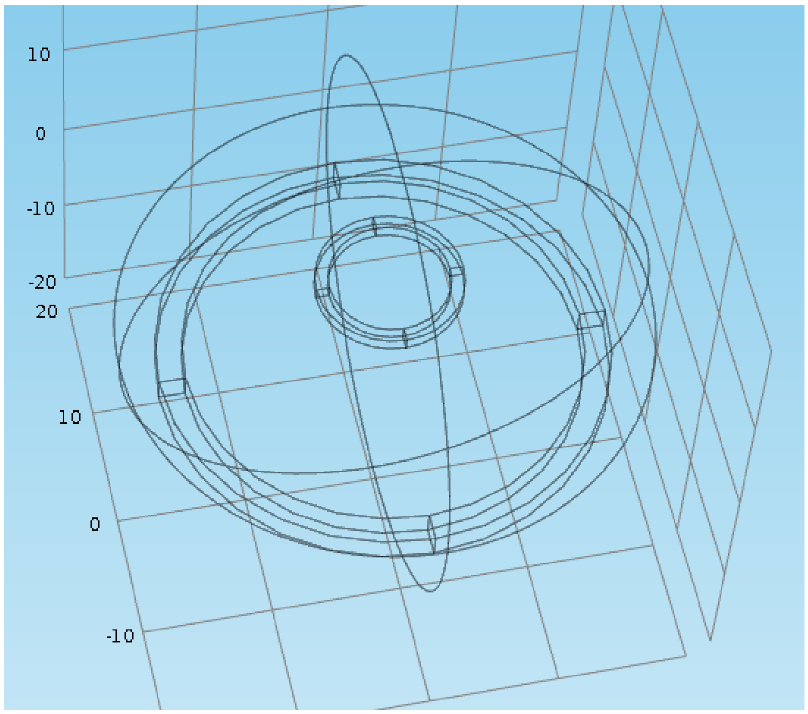


Figure 7: Coil model in COMSOL heat simulation with the smaller single coil and the larger halo coil

The signal from the biophasic stimulator is a sinusoidal wave with a frequency of 2.5 kHz, and a magnitude of 5000 A. A COMSOL Frequency-Transient analysis uses the calculated power to figure out the time needed for the coils to reach 37 °C.

iii. Results

The simulation indicates that after 132 seconds the single coil will reach 37.167 °C. The distance between the single coil and the halo coil does not have significant effect on the results. Thus, the duration of the TMS treatment must not exceed 132 seconds.

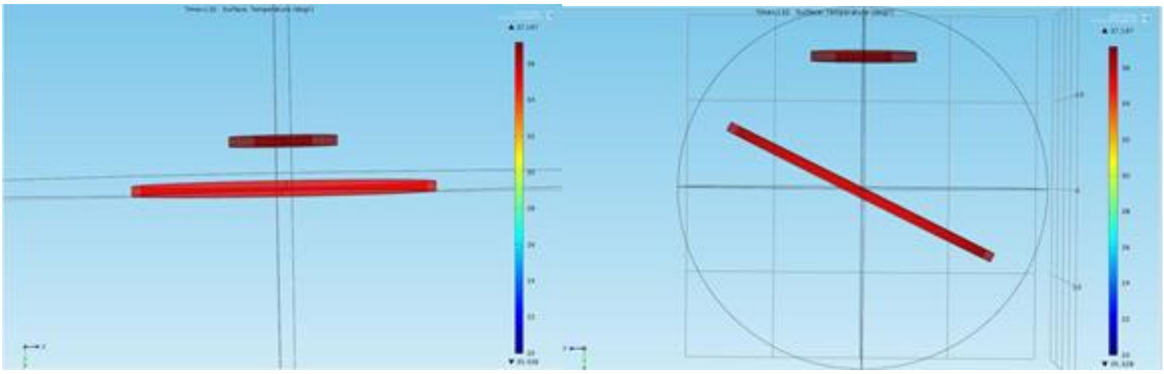


Figure 8: Results of the heat simulation

4.1.3 Electromagnetic Lorentz Force Simulation

i. Introduction

Any metal in a magnetic field generates Lorentz force, which can have an effect on the stability of the various components of the design. The two coils increase the effects of the force and also experience the force. A simulation will show the size and direction of the force as the halo coil changes position. The force must not exceed the yield strength of the involved components, thus limiting how close the two coils may come.

The design also includes servo motors containing metal parts. These metal parts need to be far enough away from the magnetic field that they do not experience a significant force.

ii. Methods

The simulation is an electromagnetic force simulation with the same coil model and the same input current as the heat simulation. The distance between the two coils changes throughout the course of the simulation in order to determine the minimum safe distance.

The test for the minimum distance between the servo motor and the halo coil involved setting the stimulator to 100 % and holding the servo a distance from the coil. If the servo moved, it was too close to the coil.

iii. Results

After the several measurements, the safe distance between the Halo coil and the motor is 4 cm.

The simulation determined that the Lorentz force density was much smaller than the yield strength of the material of the two coils. The system is therefore stable.

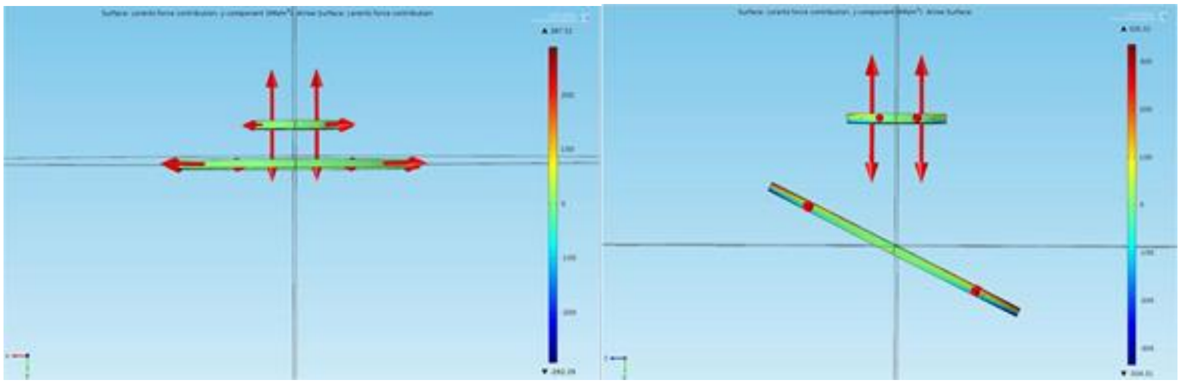


Figure 9: Results of the force simulation

5 Detailed Design

5.1 Helmet Design

The helmet was largely fabricated through the use of a 3D printer. It is broken into several pieces in order to facilitate construction. These pieces will be held together with nylon nuts and bolts in order to avoid any possible interference with the magnetic field. At each interconnect, a bolt will fit through a tab and hold together the structure.

The support structure is made of aluminum in order to increase the strength of the structure and circumvent the size limit of the 3D printers.

5.1.1 Support Structure

The helmet support structure will serve as an easy way to position and hold the helmet directly over the patient's head. It will take the weight of the helmet off of the patient's neck in order to increase the patient's comfort, it will be easy to place and remove, and it will be capable of adjusting to the difference in the heights of various patients. The support structure will attach to the vertical positioning system.

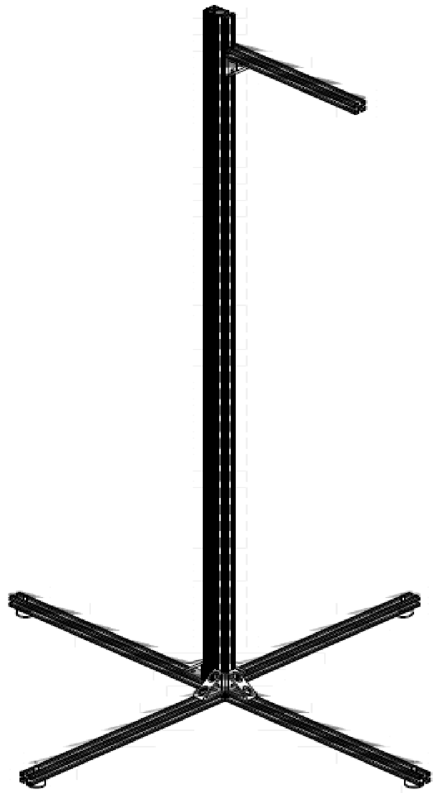


Figure 10: Support structure

5.1.2 Rotational Positioning System

The rotational positioning system will be 3D printed out of plastic and use two servo motors to rotate the halo coil from 30° to -30°.

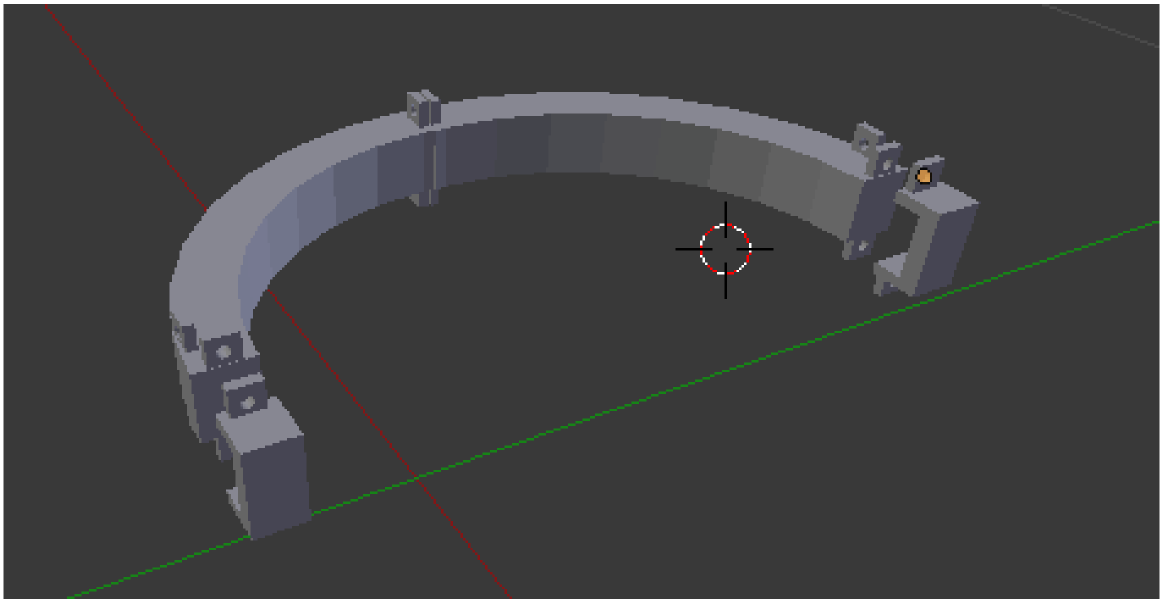


Figure 11: Rotational Positioning System

It will consist of four different parts: the half halo, the brackets, the halo holders, and the servos.

The half halo is the support for this structure and will attach to the vertical positioner. The servo motors attach on either end of the half halo so that they are properly positioned for balanced rotational movement. The half halo is split in half for ease of assembly and to accommodate the halo coil's power cable.

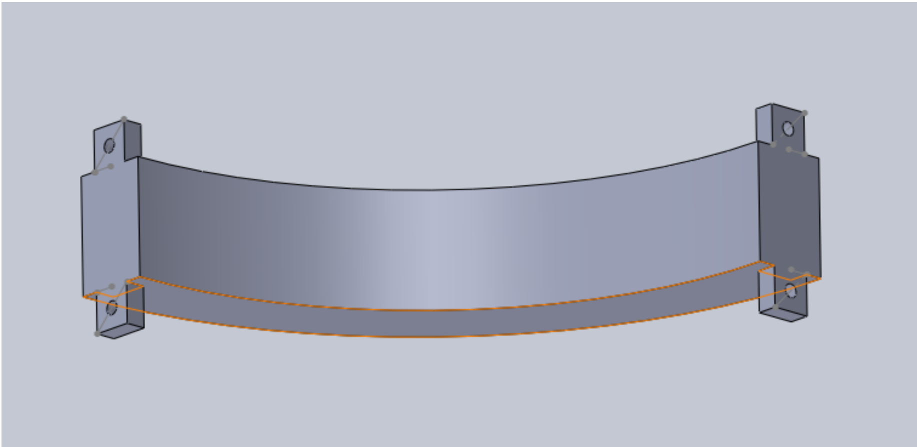


Figure 12: Half of the half halo

The brackets fit over the servo motors and hold them securely against the half halo. They attach to the half halo using the bolt and tab structure.

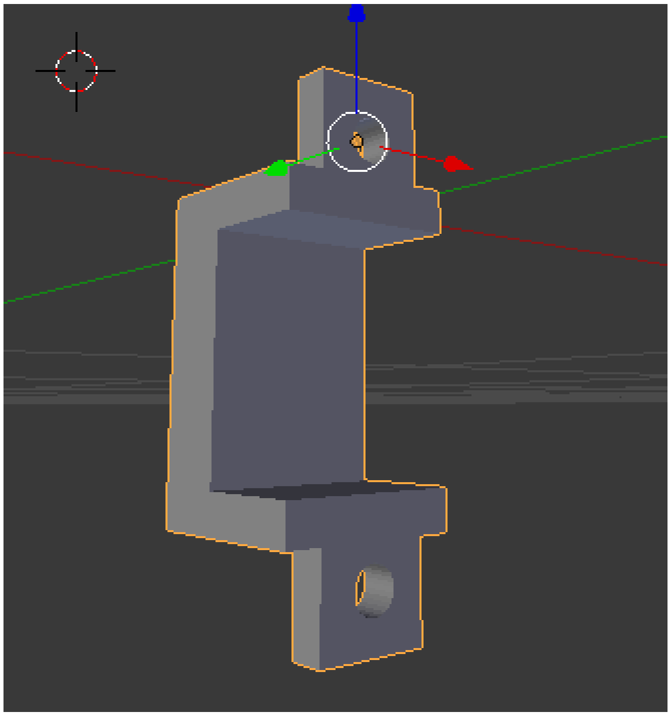


Figure 13: Bracket

The halo holders connect the servo motors to the halo coil. On one end the holder has a dial attached to the servo motor head. On the other end the holder wraps around the halo coil. This portion of the holder is curved to properly fit the halo coil.

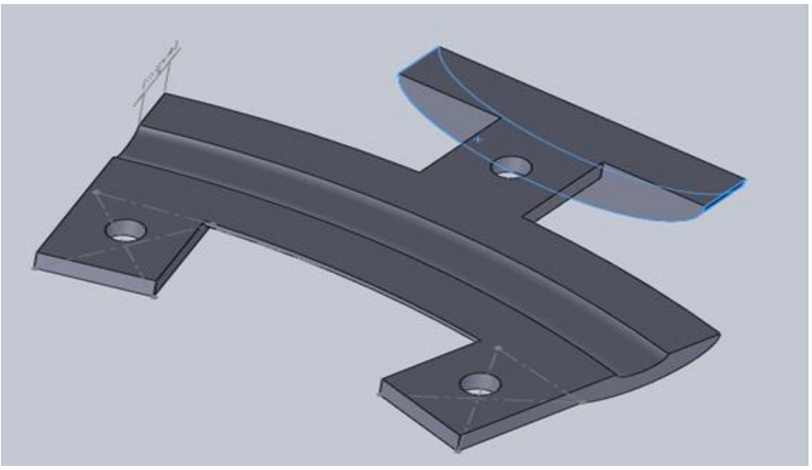


Figure 14: Halo holder

5.1.3 Vertical Positioning System

The vertical positioning system attaches to the rotational positioning system with four curved aluminum supports. These supports will attach to tabs on the outside of the half halo and extend above it. They are curved to avoid the patient's head and the single coil. The diameter of this curve matches the outer diameter of the half halo in order to simplify the structure.

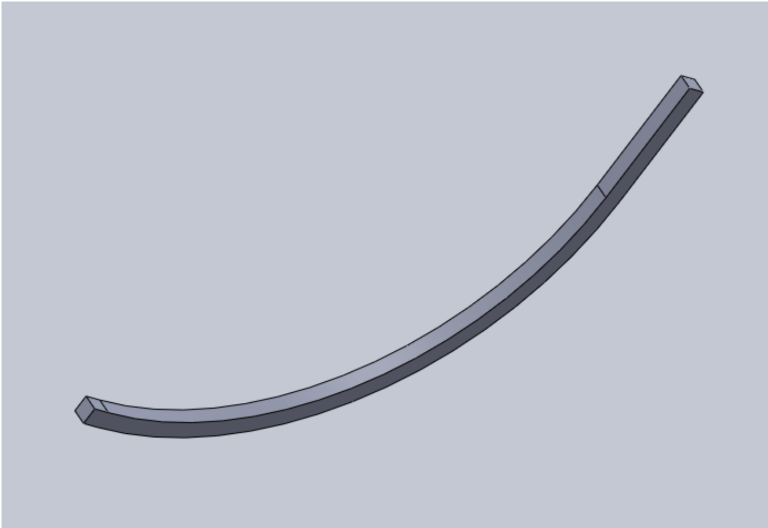


Figure 15: Vertical support

A linear actuator will perform the vertical positioning. The actuator will connect to the four vertical supports and the support structure.

5.2 Control System

A PC interface will allow the user to control the position of the coils. The height and degree of rotation of the helmet is displayed and constantly updated. The interface also includes a visual guide of the location of the maximum magnetic field.

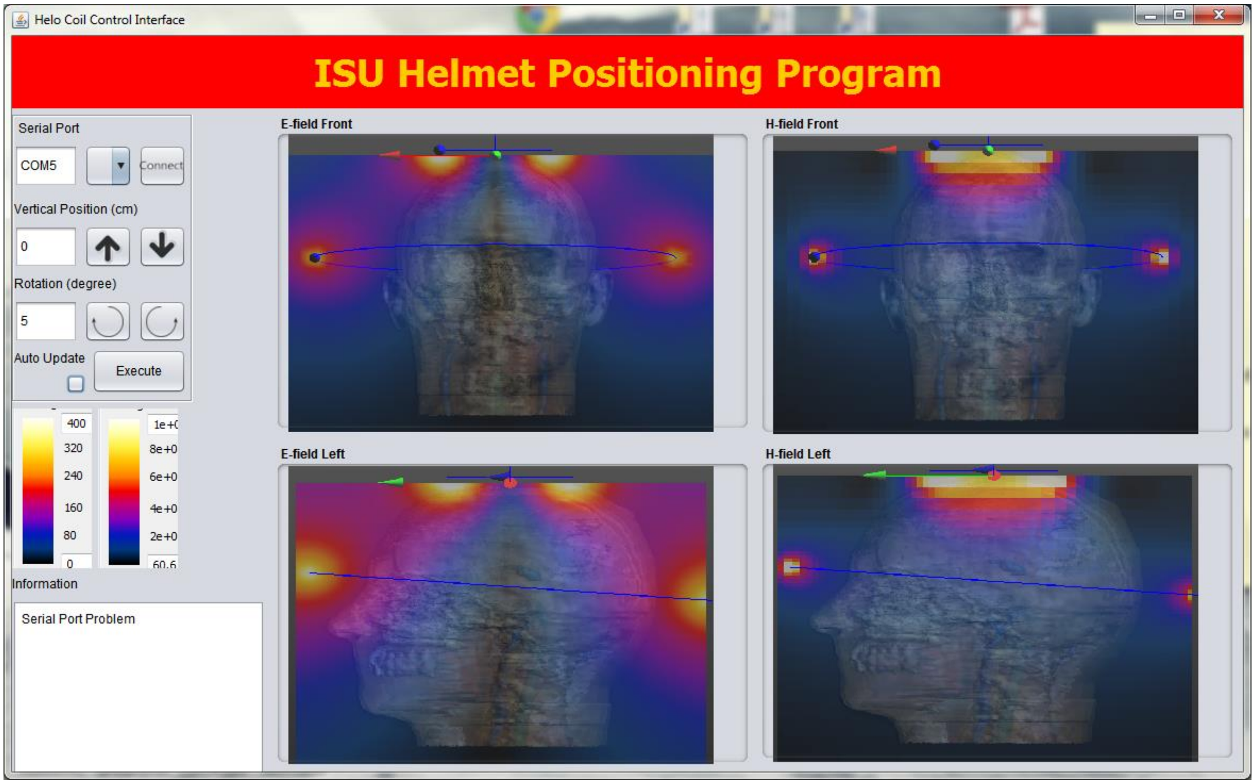


Figure 16: User interface

6 Testing

6.1 Field

A gaussmeter and automatic control system will measure the magnetic field and confirm the results of the simulation.

6.2 Helmet Positioning System

The position of the helmet will be measured with a ruler and compared to a range of acceptable values. The simulation results will determine this range.

The tilt will be measured with a protractor and compared to a set of acceptable values.

6.3 Temperature

A thermal sensor on the single coil measures the temperature of the coil. After several tests, the time required for the single coil to reach 37 °C is 138 ± 1.1 seconds, confirming the results of the simulation.

Appendix I: Operation Manual

Software running requirement:
Must have JRE 1.7 or above installed.
Java is available at https://www.java.com/en/download/

Target Operation System:
Windows 7 64bits

Setup:

1. Copy the “HaloPosition.jar” to the preferred destination
2. Open the program with Java runtime environment

If the default running program is not java run time environment,

a. Right click on the icon.
b. Click “open with”
c. Click choose default program
d. In the panel, click “Browse” near the bottom right
e. In the “Open with” panel, find C:\Program Files\Java\jre7\bin\javaw.exe
   Note: The path could vary depending on the computer

3. Double click the “HaloPosition.jar” icon

Operation Instructions:

1. The panel on the top left side is the control panel where the user is allowed to control the system
   a. Click “Connect” button, which asks the program to connect with Arduino onport 5. By default it is COM5. If not, open the Device Manager under Windows Control Panel. Then find the port where Arduino connects.

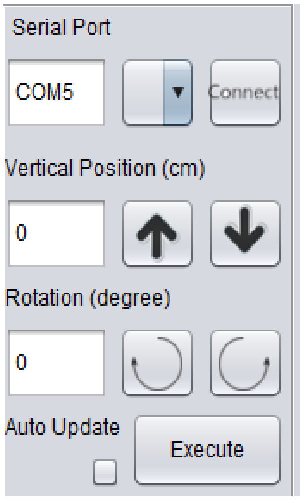


Figure 1: Device manager

b. To set the targeted vertical position, either enter the value in the text field in the middle or click the up or down arrow to adjust the value a preset amount
c. To set the targeted degree of rotation, enter the value in the text field in the third line of the panel or click the button with the clockwise or the counter clockwise arrow
d. Click the "Execute" button to ask the hardware to move to the targeted position
e. Checking the "Auto Update" checkbox allows the user to issue a command immediately after any of the control buttons are clicked

2. Information Panel:

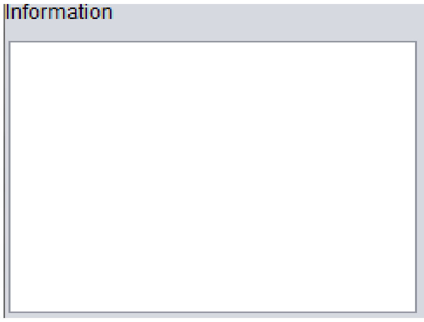


Figure 2: Information panel

This panel shows the error information such as a connection failure

3. E-field Font, E-field Left, H-field Front and H-field Left Panel
These panels show the pre-simulated images of E field and H field. These images are viewed from front or left perspective

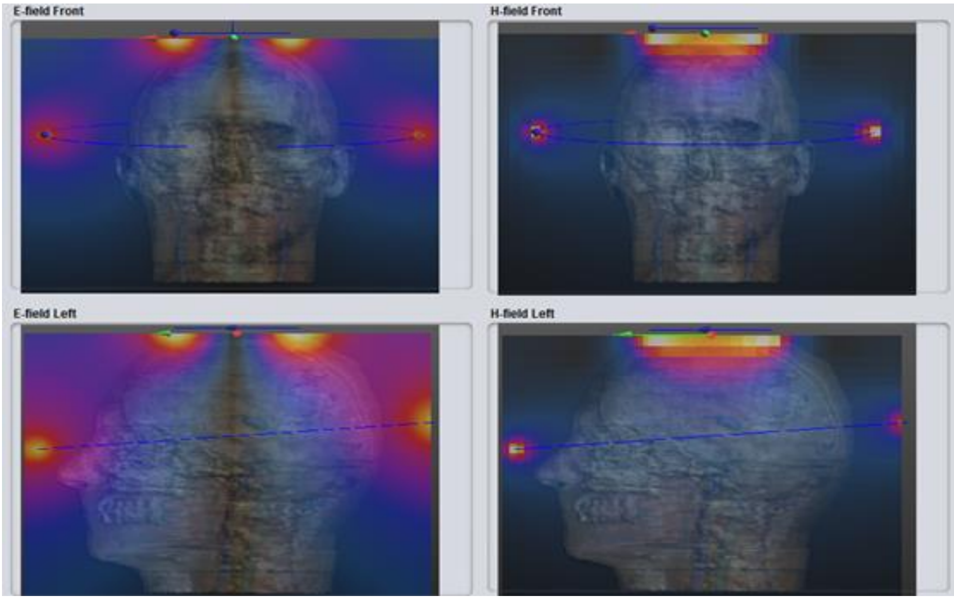


Figure 3: E-field panel

Appendix II: Alternative Designs

1 Rotational Positioning Design Changes

The initial design included a cap instead of a bracket. This cap fit over a compartment in the half halo designed to hold the servo motor. After fabrication it became clear that the head of the servo motor did not have enough clearance to spin freely while the motor was inside the compartment. In order to fix this issue, the compartment was removed and the bracket replaced the cap. This change removes all interference from the servo head.

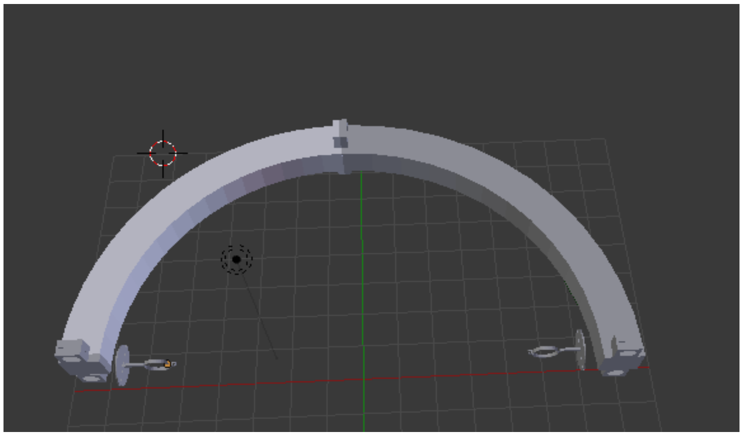


Figure 1: Whole View (Old)

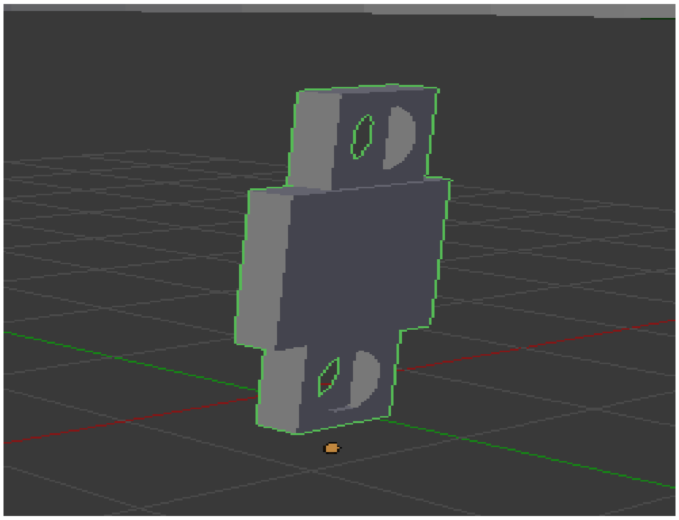


Figure 2: Cap

The original halo holder did not curve to fit the halo coil. Instead, the holder covered a small enough area that the coil was straight enough to fit. When used, this holder was incapable of overcoming the weight of the halo coil's power cord. The redesign of the holder lengthened the portion in contact with the coil and therefore required the holder to curve to fit the coil.

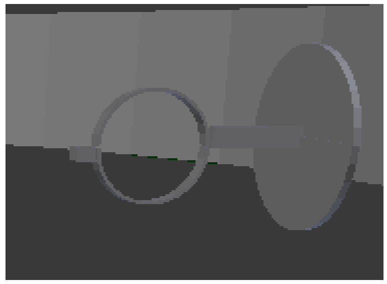


Figure 3: Halo holder

2 Vertical Positioning Design Changes

The original vertical positioner included a servo motor with a rack and pinion to translate the rotational motion to vertical motion. It soon became clear that due to servo motor strength limitations and material restrictions that another method of vertical motion was necessary. A linear actuator replaced the rack and pinion.

In the initial design the vertical positioner connected at the back of the half halo. This design changed to accommodate the power cable of the halo coil. The vertical positioner now connects above the rotational positioner.

3 Programming Design Changes

Initially, the GUI consisted of a visual guide of the position of the coil to show the user the current location. The images from the simulation occupy too much area for this visual guide to fit so it was removed to accommodate four sets of field images.

The arduino code originally controlled a third before the change to a linear actuator. New code was then needed to properly control the device.