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Transcranial Magnetic Stimulation Helmet Design

Design Document

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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 works by combining with a coil placed on top of the head. The halo coil then goes around the head, like the halo it is named after.

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 when it is combined with another stationary coil placed on top of the patient's head it 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 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

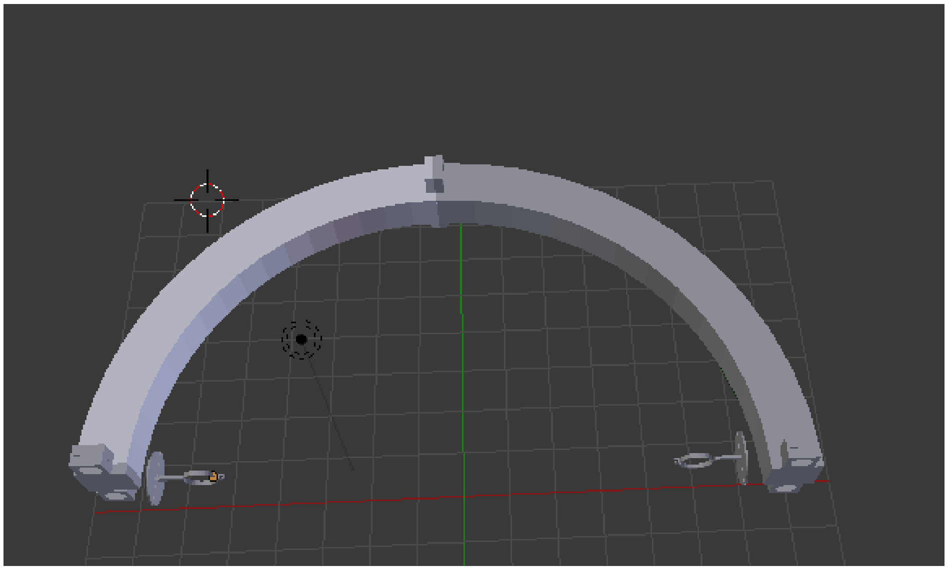

Figure 1: 3D view of the Halo holder

2 Requirements

2.1 Functional Requirements

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

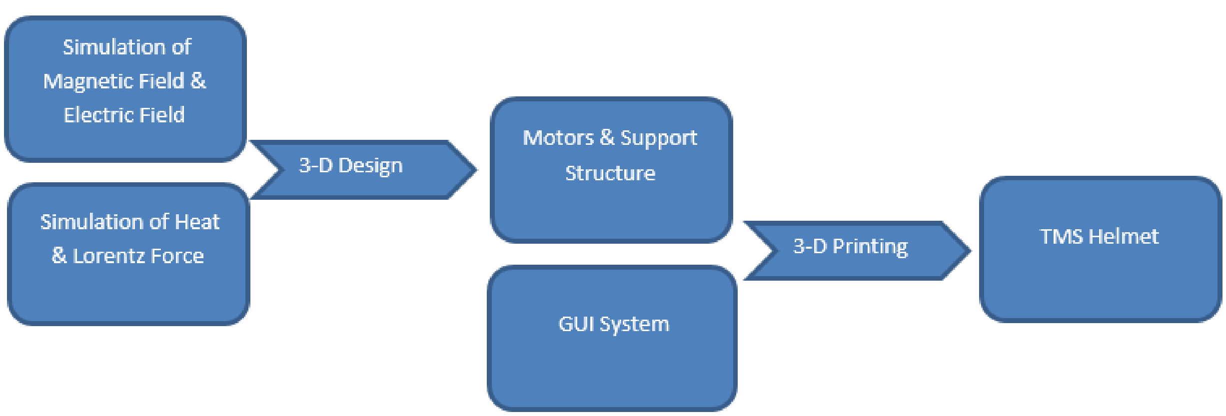

Figure 2: System block diagram

3.2 System Concept Sketch

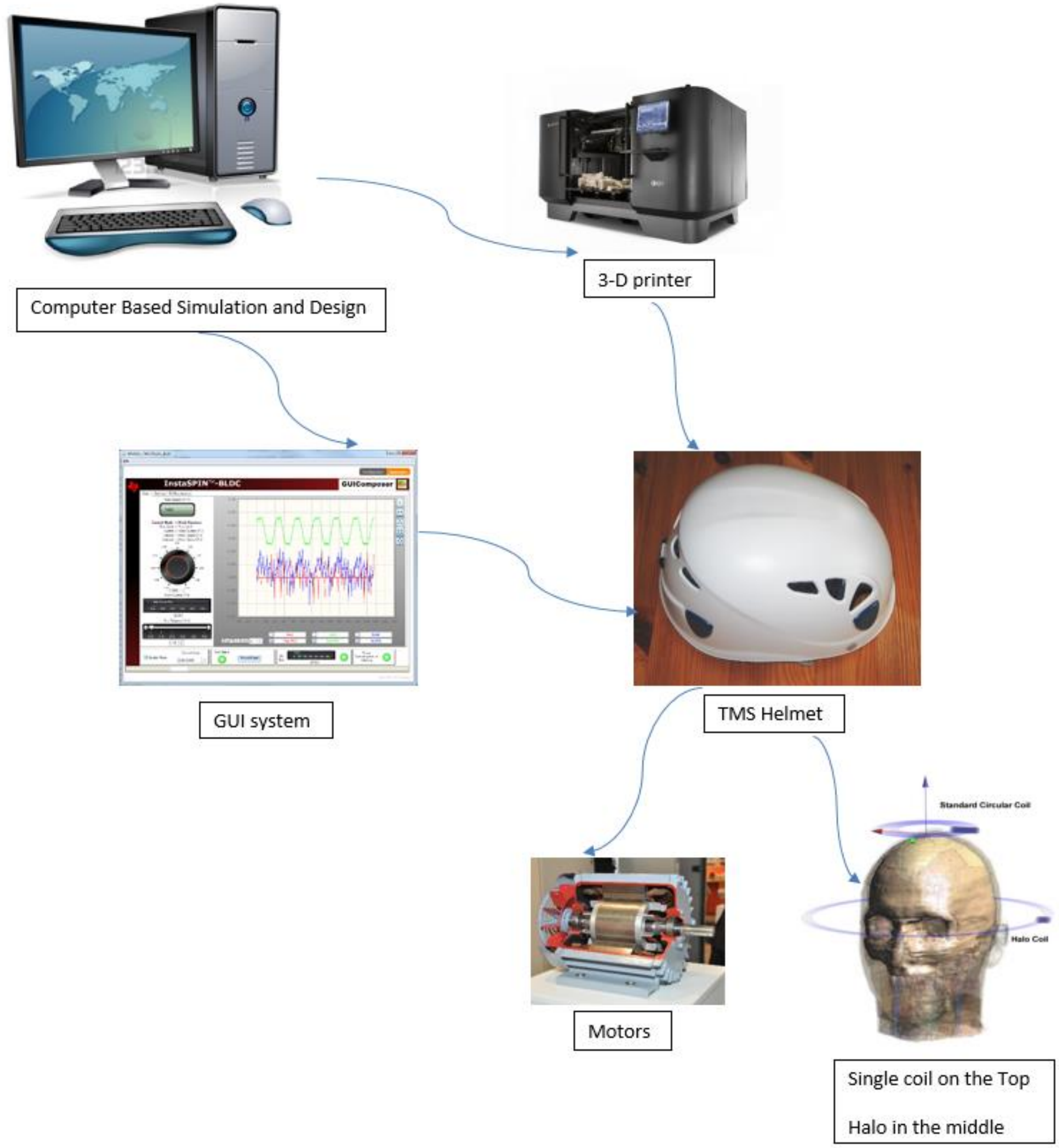

Figure 3: System concept sketch

3.3 Component Specifications

- **Single Coil:** average diameter :9 cm, number of turns: 14
- **Halo coil:** Inner diameter: 27.7 cm, outer diameter: 29.9 cm, number of turns: 5
- **Halo Holder:** average diameter: 33.9 cm (29.9cm + 4cm)

4 Design Process

4.1 Simulation

4.1.1 Electric and Magnetic Field Simulation

i. Introduction

In order to find that how current in the halo coil affects regions of the brain, we need to use SEMCAD to do the simulation and find where the maximum of the electric field occurs when the halo coil is located in different positions.

ii. Methods

First we build the model of the simple head with a halo coil. The brief picture is as below:

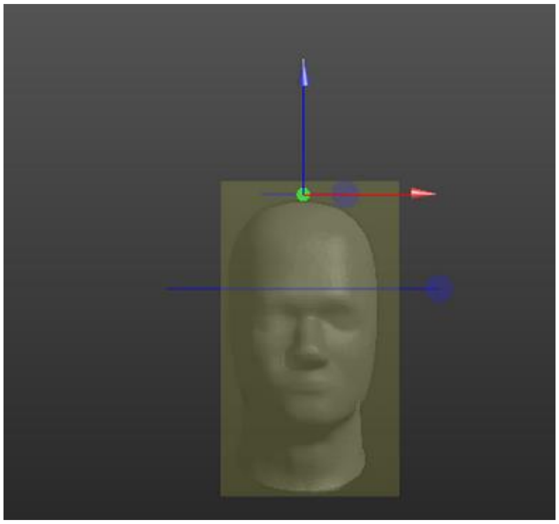

Figure 4: Simple head model

This figure shows the initial 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, we will rotate the halo coil upward by 30 degrees and downward by 30 degrees by increments of 5 degrees so that we will get 12 data points about where the maximum of the electric field occurs when the halo coil is located in different positions.

4.1.2 Electromagnetic Heat Simulation

i. Introduction

Due to the heat standards of human medical treatment, the surface temperature of coils should not exceed 37°C, the normal body temperature of a human. This is a very important constraint for our design, so in order to find an accurate time limit of the TMS treatment, we will use COMSOL Multiphysics to do the Electromagnetic Heat Simulation.

ii. Methods

In the model library, we select Electromagnetic Heating => Joule Heating Model for the type of simulation. First, we need to build the coil model:

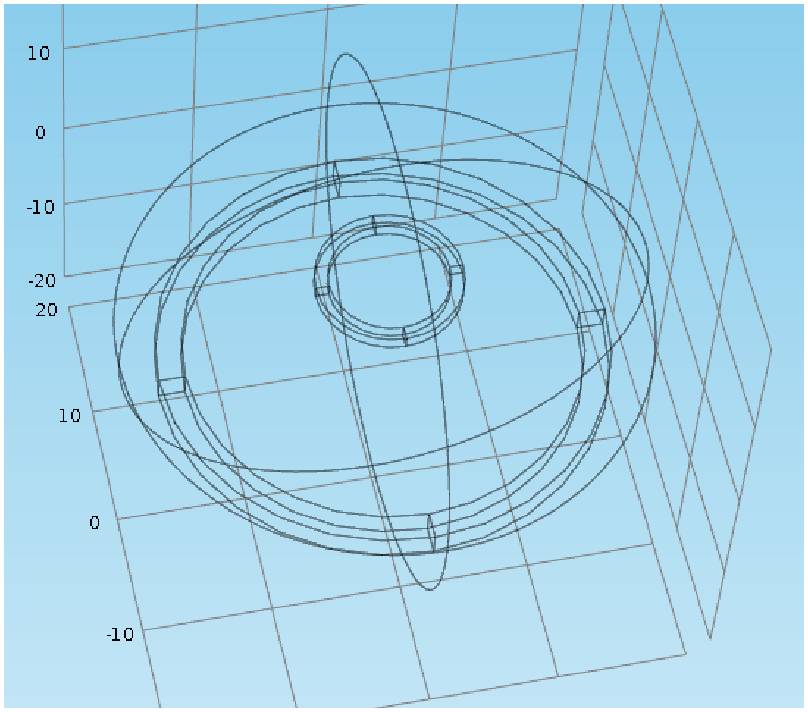

Figure 5: Coil model in COMSOL heat simulation. The small circle on the top is the single coil, and the coil below is the halo coil.

The signal from the biophasic stimulator is a sinusoidal wave, the frequency is 2.5K Hz, and the magnitude is 5000 A. We first calculate the power for the two coils and do the Frequency-Transient analysis to figure out the time when coils would reach 37 °C.

4.1.3 Electromagnetic Lorentz Force Simulation

i. Introduction

Any metal in the magnetic field can generate Lorentz force, which is another hazard for our design, especially since we are using two coils in the design. We need to figure out the minimum distance between two coils to make sure the whole helmet is balanced during the treatment. Beside this, we also need to find the safe distance between the Halo coil and the servo motors because we use motors to move the Halo coil and we must guarantee that the whole structure is absolutely stable.

ii. Methods

In the model library, we select Electromagnetic Force model for the type of simulation, and we use the same coil model and the input current as the heat simulation. We have to change the distance between two coils to find the minimum one.

iii. Results

We just do the real experiment with motor and Halo coil. After setting the 100% intensity of the input signal from the stimulator, we observe the movement of the motor, and we also change the distance in between. After the several measurements, we find the safe distance between the Halo coil and the motor is 4 cm.

4.2 Material Selection

4.2.1 3D printing lab information

a. Prototyping & Fabrication Service Center *(PFSC Lab, location: Howe 1380, Iowa State University, Ames, IA, 50012)*

3D printer type: Alaris 30U
Maximum size: 7.12'' x 11.57'' x 5.9''
Materials: black, white or grey hard plastic

b. Prototyping & Fabrication Service Center *(PFSC Lab, location: Howe 1380, Iowa State University, Ames, IA, 50012)*

3D printer type: Connex 260
Maximum size: 10.2'' x 10.2'' x 7.9''
Materials: black, white or grey or clear hard plastic; Black or grey flexible plastic; Green ABS-like plastic; Mix black and white flexible materials

c. Boyd Lab *(Location: Hoover 1260, Iowa State University, Ames, IA, 50012)*

3D printer type: Dimension uPrint Plus 3D Printer
Maximum size: 8'' x 6'' x 6''
Materials: NEED TO CHECK (Model support material is dissolved during printing)

d. Boyd Lab *(Location: Hoover 1260, Iowa State University, Ames, IA, 50012)*

3D printer type: Fortus 250 3D Printer
Maximum size: Plastic, 10'' x 10'' x 12''
Materials: NEED TO CHECK (Model support material is dissolved during printing)

e. Boyd Lab (*Location: Hoover 1260,Iowa State University, Ames, IA, 50012* ***)***

3D printer type: ZPrinter 450 3D Printer
Maximum size: 8'' x 10'' x 8''
Materials: Plastic, NEED TO CHECK
Addition: Can print an image on surface of model

4.2.2 3D Printing Materials Information

a. White Plastic:

Description: White, strong, slightly flexible material that can withstand some pressure when bent. The surface has a grainy, sanded appearance and is slightly porous.

Price: In 5 cm / 1.97 in : $18.00
In 10 cm / 3.94 in : $141.00
In 15 cm / 5.91 in : $478.00

b. Colored Plastic:

Description: Colored, strong, slightly flexible material that can withstand light impact and pressure when bent. This material is white plastic dyed black, red, blue, yellow, green, pink, orange, beige, brown or grey. The surface has a grainy, sanded appearance and is slightly porous.

Price: In 5 cm / 1.97 in : $24.00
In 10 cm / 3.94 in : $161.00
In 15 cm / 5.91 in : $531.00

c. Polished Plastic:

Description: White or colored, strong, slightly flexible material that can withstand some pressure when bent. The surface has a polished, smooth touch.

Price: In 5 cm / 1.97 in : $22.00
In 10 cm / 3.94 in : $152.00
In 15 cm / 5.91 in : $505.00

5 Detailed Design

5.1 Helmet Design

The helmet and its associated support structure will largely be 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 plastic nuts and bolts in order to avoid any possible interference with the magnetic field. At each interconnect, a tab will be left. On one side, the tab will have an indent for the nut. On the other, the tab will have an indent for the head of the bolt. There will be a hole through both tabs for the rest of the bolt. In this way the two pieces will be held together when the bolt is screwed into the nut.

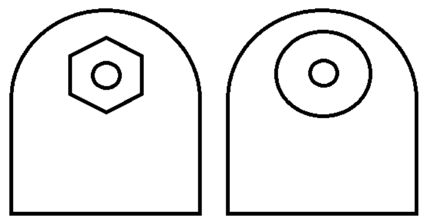

Figure 6: Nut and bolt tabs

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. Because of these requirements, the support structure will consist of multiple hinged pieces of plastic. This will allow the technician to more accurately place the helmet with the patient's head in the center. The support structure will attach to the vertical positioning system as well as the stationary platform for the single coil.

The stationary platform will follow the shape of the single coil. It will be placed on top of and in the center of the patient's head. The platform will include a groove for the cord attached to the single coil that runs back to the support structure. This groove will keep the cord and its associated fields from interfering with the coil system.

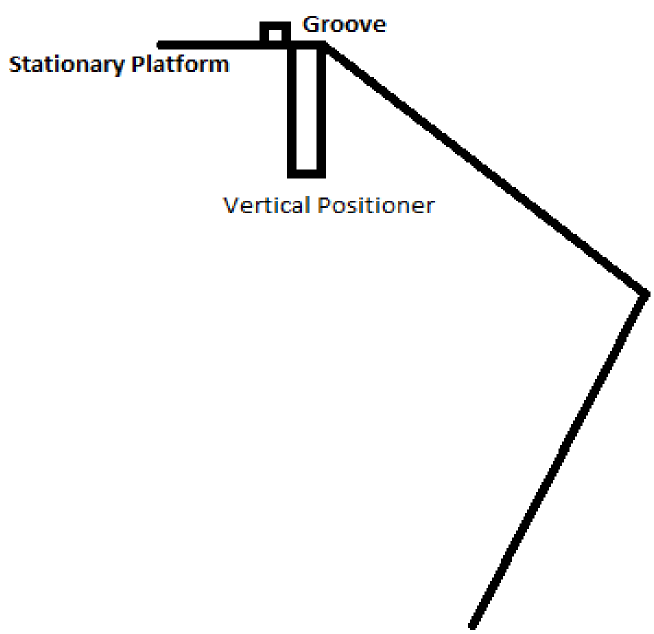

Figure 7: Support structure

5.1.2 Halo Holder and Positioning System

The halo holder will consist of a half halo plastic structure and the servo motors to position the halo coil. The vertical positioner will connect to the support structure. This positioner will include one servo motor and will move the half halo plastic structure.

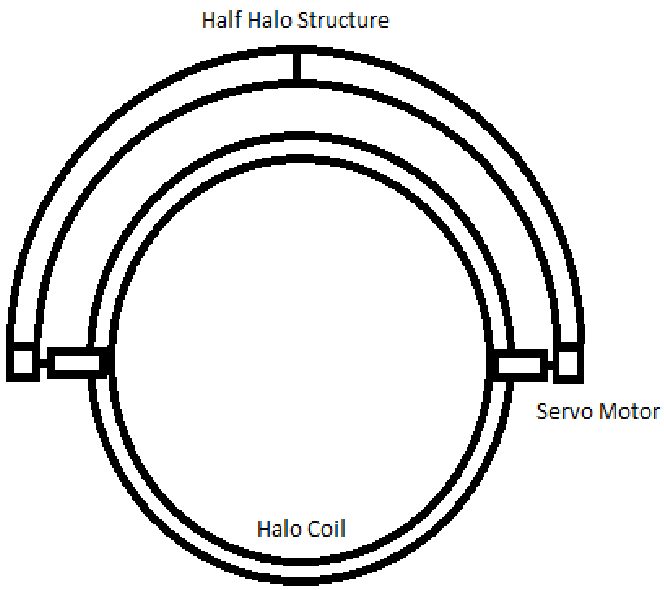

Figure 8: Halo holder

The servo motors will be fitted within a hollow compartment at the ends of the half halo structure. They will then be held in place by end caps.

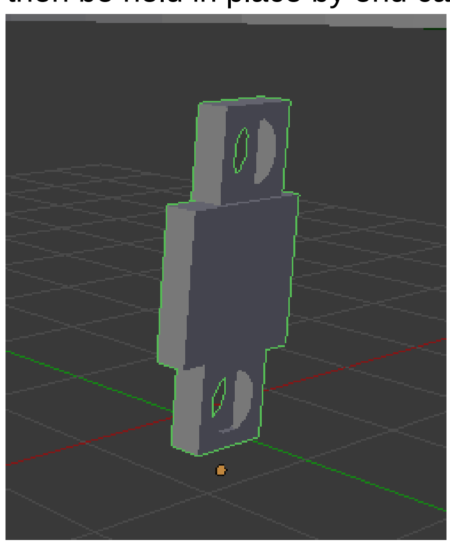

Figure 9: 3D view of servo plate

The servo motors will be directly connected to the pieces holding the halo coil. This will be accomplished by drilling holes in a plastic disk to match those on the disk of the servo. The holder will then be pinned into place. This holder will be fabricated in two pieces so that it may wrap completely around the halo coil.

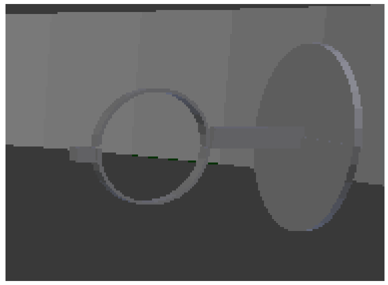

Figure 10: 3D view of halo tilter

The servo for the vertical positioner will be attached in much the same way. A disk shaped like a gear will be pinned to the servo disk and that gear will move along a similarly serrated vertical piece. The servo gear will be held to this vertical piece by a piece of plastic holding a wheel so that movement is not hindered.

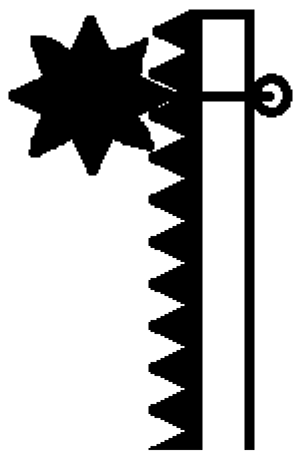

Figure 11: Vertical positioner

5.2 Control System

A PC interface that allows user to control the position of the coils. Data like the height of helm and the rotation degree of coil is displayed and constantly updated. A visual guide of where the maximum magnetic field locates is also included.

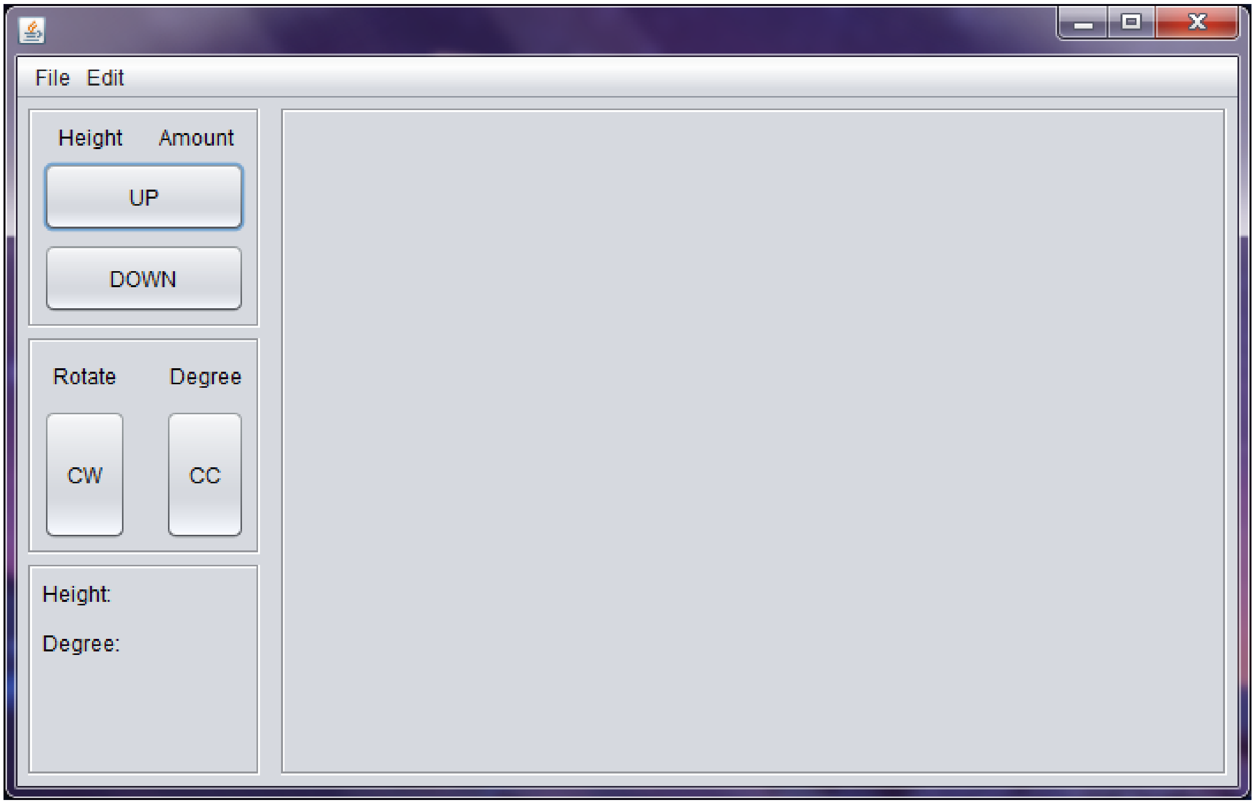

Figure 12: GUI interface

6 Testing

6.1 Field

We use the measurement system in our research lab with guassmeter and automatic control system which can point to many single position to measure the magnetic field. We have to do the measurement to confirm our result whether the movement of coils can generate such magnitude of magnetic field.

6.2 Helmet Positioning System

To test the vertical positioning device, a ruler will be included in the prototype design. The position can then be measured and compared to the range of acceptable values obtained in simulation.

In order to test the tilt a protractor will be included in the prototype design. The angle of the tilt can then be measured using a reference point at 0°C. This value can then be compared to the range of acceptable values obtained in simulation.

6.3 Temperature

Thermometers are already included in the coil design. That temperature may be compared to the melting temperature of the plastic used in the helmet design and the medical requirement that the coils may not exceed 37°C.