Teaching Model for Human Eye Movement: A Multidisciplinary Senior Design Project

Honors Thesis

Presented in Partial Fulfillment of the Requirements for the
University Honors Program

Colorado State University

By

Michael Zito

Biomedical and Mechanical Engineering

Dr. Kirk McGilvray, Biomedical and Mechanical Engineering

Dr. Ellen Brennan-Pierce, Biomedical and Mechanical Engineering

Spring 2025

Table of Contents

Abstract

This thesis documents the development of an anatomically accurate teaching model demonstrating human ocular movement. The year-long senior design project, sponsored by Colorado State University, was conducted under the guidance of Dr. Leslie Stone-Roy (Neuroscience) and Dr. Kirk McGilvray (Biomedical and Mechanical Engineering). The model effectively represents the human eyes, oculomotor musculature, and the associated neuronal pathways responsible for eye movement. The project allows for the demonstration of both functional and impaired neural pathways via LED sequencing as well as the respective motor functions for each respective path. Development of the project progressed through multiple design evaluations, prototyping iterations, and testing methods. The final project serves as an educational resource for undergraduate neuroscience curriculum at Colorado State University. This project helped to develop personal engineering skills and principles while also creating an impactful educational tool to enhance the comprehension of complex neuroanatomical concepts.

Introduction

The complex interaction between oculomotor muscles, neurological pathways, and visual processing represents one of the human body's most sophisticated control systems. Despite its fundamental importance in medical and neuroscience education, three-dimensional visualization of these mechanisms often remains challenging for students to conceptualize through traditional teaching methods. This thesis documents the development of a comprehensive physical teaching model of human eye movement created to address this educational gap in the neuroscience curriculum at Colorado State University and other universities around the world. As part of a year-long senior design project, our multidisciplinary engineering team, under the guidance of Dr. Leslie Stone-Roy(Neuroscience) and Dr. Kirk McGilvray (Biomedical and Mechanical Engineering), collaborated to create an anatomically accurate representation that demonstrates the coordinated action of extraocular muscles and their corresponding neural pathways. The model serves as a learning tool that transforms abstract neuroanatomical concepts into observable mechanical relationships, allowing students to visualize the complexities of ocular motility in three dimensions. This work represents the intersection of biomedical engineering principles, educational design theory, and neuroanatomical accuracy reflecting both the technical challenges and the educational opportunities that arise when translating physiological systems into physical teaching tools.

Methods and Research

When designing any kind teaching model for physiological comprehension, it is critical that the model demonstrates the correct anatomical layouts and functions. For this reason, an abundance of research on the anatomy of the eyes as well as the functions of the brain was conducted. To gain an understanding of the complexity of eye mobility it is important to understand all of the moving parts and any synapses that are responsible for innervation. As observed in Figure 1, there are six ocular muscles that are responsible for the movement of the eye, the superior and inferior recti, medial and lateral recti, and the superior and inferior obliques (Lennerstrand, 2007).

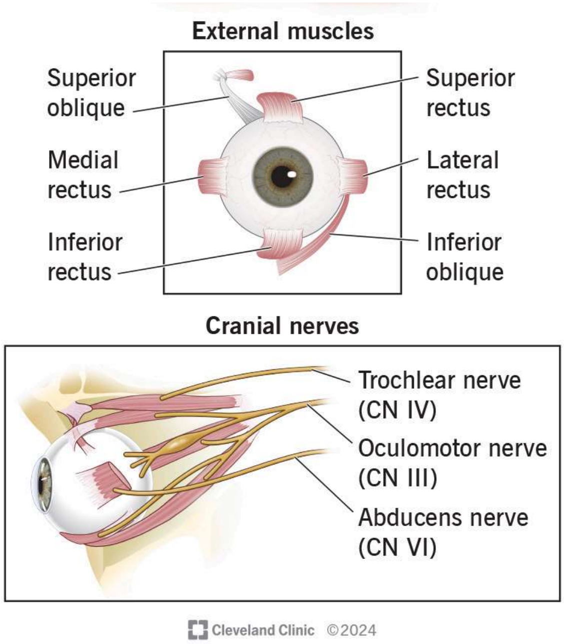

Figure 1: Ocular Muscles and Cranial Nerves Responsible for Eye Movement (Cleveland Clinic medical, 2025)

The six muscles are responsible for horizontal, vertical, and torsional movements of the eyes. The superior and inferior recti are responsible for vertical, lateral and medial recti are responsible for lateral, and the obliques are responsible for torsional movements (Purves, 1970b). Innervation of these muscles is crucial for the eye to constantly stay level and properly oriented within the eye socket. When looking straight ahead, whether voluntarily or involuntarily, at a target there are small levels of contractions within each muscle. In fact, there are special and “distinct fibro-elastic pulleys” that surround each rectus muscle to maintain proper positioning and contraction (Lennerstrand, 2007). Without proper contraction from the rectus and oblique muscles it can lead to physical defects as well as improper movements.

The brain is another complex system that plays a significant role when it comes to eye movement. There are numerous neuronal pathways that are responsible for the different types of movements that can be made by the eyes. There are three main cranial nerves that are responsible for delivering signals to the ocular muscles, cranial nerves III, IV, and VI (“Eye

Movement Control", n.d.). Cranial nerves III, IV, and VI are also commonly referred to as the oculomotor, trochlear, and abducens nuclei, respectively. Each nerve is responsible for innervating different types of eye movements and ocular muscles. Abducens nuclei are responsible for the ipsilateral lateral rectus, the trochlear nuclei are responsible for the contralateral superior oblique and the oculomotor nuclei are responsible for the four remaining ocular muscles (Themes, 2019). Each nuclei will receive signals from other synapses in the brain starting at the parietal, extrastriate, and supplementary eye fields working their way down to the front eye fields, superior colliculi, and vergence nuclei until reaching the respective cranial nerves (Coiner et al., 2019).

All of the presented anatomical features and functions needed to be represented accordingly for the physical model to be an effective teaching tool. For this reason, the project followed multiple designed based methods. Multiple iterations of 3D models and 3D prints were created and tested to ensure accurate placement of muscle attachments as well as pathing for the different cranial nerves. The team worked diligently with our advisors to ensure a sound mechanical design as well as proper anatomical accuracy.

Results

The results of the project was a 3D interactive teaching model. The device was split into two different parts, the neurological pathways LED board and the movement and interactive stage. The LED board is 3D printed with multiple neurological pathways laid out and each synapse and nuclei is labeled accordingly. The board is secured to a custom printed easel that houses the electrical components for the LEDs and connection wiring as observed in Figure 2. The addressable LEDs span top to bottom through the different pathways. Depending on the action that is requested the LEDs will display the corresponding pathway in a sequential order with LEDs turning on one after another. LEDs are addressed with differently colors depending on if they are representing a traveling signal (White), synapse location (Yellow), nerve damage (Red), or one of the ocular muscles being activated (Superior Rectus::Orange, Inferior Rectus:: Green, Lateral Rectus:: Blue, Medial Rectus:: Teal, Superior Oblique:: Pink, Inferior Oblique:: Cyan).

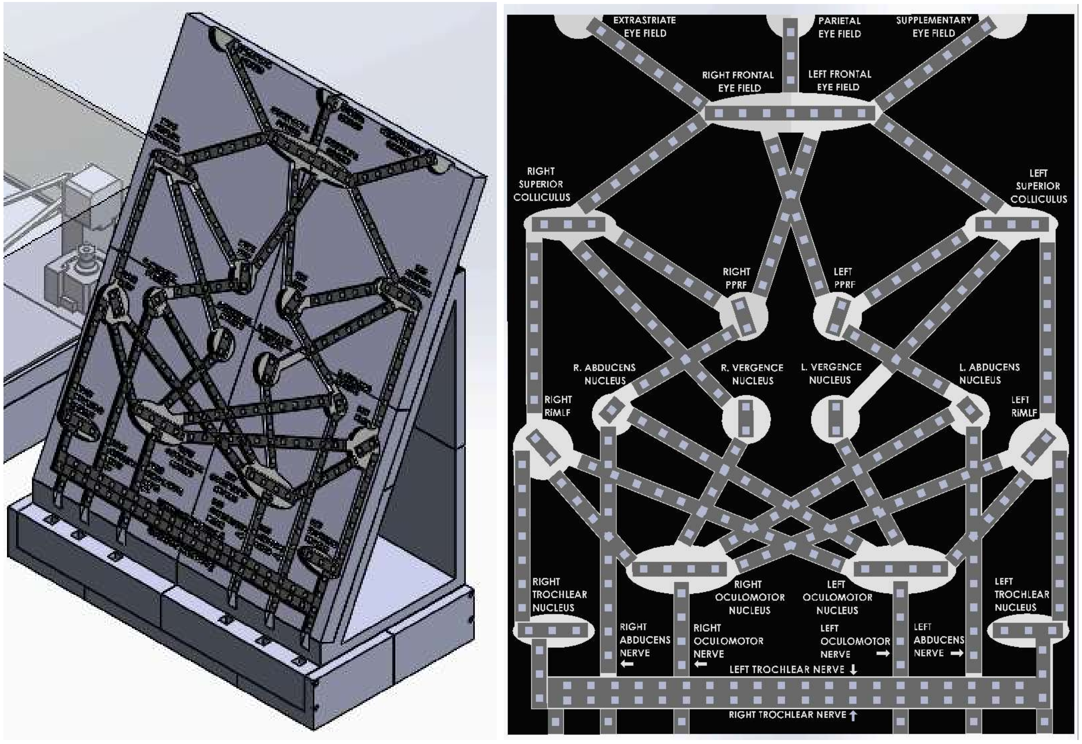

Figure 2: Isometric and Front View of LED Board and Easel

Figure 3 demonstrates that the movement and interactive stage was also made from a majority of 3D prints that were welded together. The stage had two 3D printed eyes with muscle attachment locations embedded in them. Rubber belts were attached to the muscle attachment points and spanned back to an assortment of stepper motors that would help to represent motion. There are housing towers for each motor used as well as housing for the custom pulley system to represent the trochlea of the eyes, a natural pulley system in the eye socket.

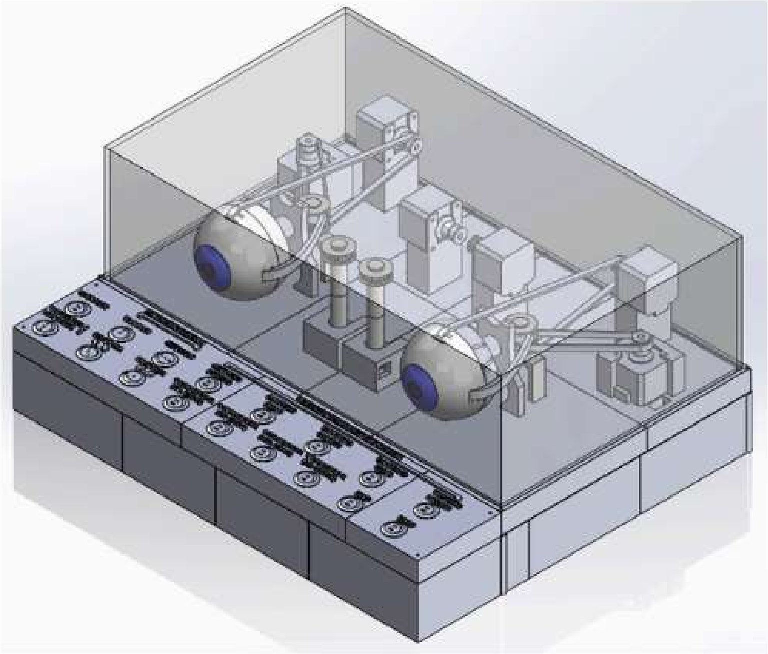

Figure 3:Isotropic View of the Movement and Interactive Stage

In addition to the anatomical display, there are interactive switches at the front of the stage. Figure 4 shows the individual switches that can control specific eye movements or illustrate different types of ocular damage. Only one switch can be activated at a time, meaning that even if a user were to flip multiple switches the device would only respond to the input from the first flipped switch. The overall project was controlled by a single Elegoo Mega responsible for receiving input from the switches and operating the corresponding LED sequence and motor movements.

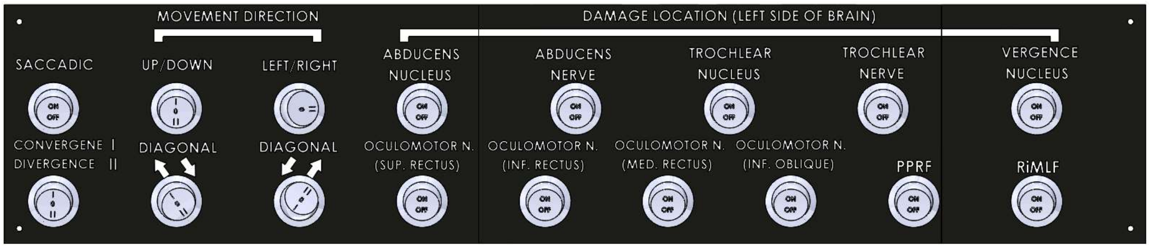

Figure 4: Top View of the Interactive Switch Board

Discussion

Overall, the project fulfilled the requirements of an operational and interactive teaching model for human eye movement. The model was able to effectively represent a majority of the different types of movements conducted by the eyes. The eyes can perform four different movements such as saccades, smooth pursuit, vergence, and vestibulo-ocular movement. Saccades are choppy movements made by the eyes which can be observed when somebody is looking around a room without tracking an object. Smooth pursuit occurs when someone is tracking an object and your eyes will follow without making any choppy movements. Vergence is what happens to the eyes when they are looking at something very close to them and is what is also referred to as cross eyed. Finally, vestibulo-ocular movement is what helps to keep the eyes level as you rotate your head from side to side (Purves, 1970a). Each movement type was displayed except for the vestibulo-ocular reflex, this is because it would require the entire device to be rotated or even just the motor mechanism to be rotated. This type of movement could lead to damages, belts crossing or falling off of their tracks, and could potentially disrupt wiring connections within the device.

As for the structure of the device, a majority of the project had to be 3D printed for both testing and the final concept because of budget constraints. Parts of the project are made up of multiple different prints that have been glued and then welded together. This method helped to build and reinforce the two structures, but it would lead to design flaws like slightly increasing or decreasing dimensions from material being added or removed as well as decreasing the overall appearance of the project. For some of the parts such as the eyes and pulleys, being 3D printed led to some friction implications. Movements would be rough and rigid because of internal burs from printing inconsistencies. With parts and the structures being 3D printed there are also concerns with durability and possible warping if it is introduced to high temperatures. Future iterations would require an increase in budget, but if the budget increase were approved it would be in the project team's best interest to look into the fabrication and machining of parts and the structures themselves. This would make the project more durable and warping from heat would either dramatically be less of a concern or not a concern at all.

In addition to upgrading the overall structures, changing out the motors for others that are more accurate and precise with their movements would also be beneficial to the overall performance of the device. Again, because of budget constraints group decisions were made to reduce the overall cost of the parts and components, but ensuring they were still able to perform the required functions. The current motors fulfill both of these requirements, but have the tendency to have a larger tolerance in their movements than are desired.

Even though there are still opportunities for improvements within the project it was still able to accomplish and fulfill its requirements. The project properly demonstrates the neurological pathways within the brain and the different pathways related to their respective movements. The project is able to demonstrate both healthy eye movement, damaged neuron eye movement, and special cases such as saccades and vergence movements. The device is a proper interactive teaching 3D model for neuroscience students to be able to use to gain a more complex understanding of the human body.

Reflection

Working on my senior design project has helped me to grow and develop as both a person and an engineer. While working on the project I have learned to overcome adversity and learn about my own work ethic and what getting a job done means to me. I have also been able to learn a lot more about design, functionality, and product management.

Throughout the year of working on this project there had been many points in the project where parts were always changing or the group seemed to keep running into different problems. We had some prior experience in smaller projects through my years in the engineering course here at Colorado State University, but the senior design project seemed to hold more weight. When starting the project we had to go through many different mock up drawings to start with an idea of what we want the project to look like and how exactly we wanted it to be able to fulfill its requirements. A lot of this first design portion came with a lot of conversations and planning between both my team and our advisors to really begin to narrow down how exactly we would come to accomplish this task. Once we had finally decided on a design we began working towards making it into a reality. In the process as a team we quickly learned how important prototyping and iterations are to the engineering design process. It felt like the first prototype almost never worked as we had wanted, whether it was one of the physical components or the functional code itself. Further down the line, a few months before E-days, we realized that the current design would not be an efficient product in the end and had to overhaul the design. This led to many late nights to properly model and 3D print the parts we would need to complete the project.

Personally, I was responsible for the code and its functionality. The code went through an outrageous amount of different iterations to be able to properly run the motors and LEDs separately and then come back and make it so that they properly work together. The code would also need different iterations depending on how our group decided the project should function whether it was how far or how fast the eyes would move or the pattern the LEDs would display to properly show signals traveling through the brain. Eventually, we got to the point where the functionality we desired had been thought out. It was time to get the code to meet those standards. We quickly ran into problems with interactions between different Arduinos as well as memory problems. This led to many all-nighters and new programs to finally reach a final and functional code that met our team's requirements and desires.

The senior design project tested me every step of the way and it really made me think about who I was as a person and how much effort I was willing to put in. I knew I had a team that was relying on me for parts of the project the same way I was relying on them for the other parts and I knew I couldn’t let them down. Understanding that feeling and that way of thinking has helped me learn more about myself and has given me something to bring to the future with me in life.

Aside from the impact the project had on me I know this project will be able to benefit a lot of different people outside of the realm of engineering. This project was specifically made for one of the neuroscience professors here at CSU. The project was made to help teach the new students about neuroanatomy. One of the great attributes of a physical teaching model is that we are able to size down complex systems and be able to make the system easier to identify and observe (“Physical Model”, n.d.). This project will allow students to take their time and interact with the device so they can see different movements and neurological pathways in action as many times as they need until they grasp an understanding of the system. There have been many studies done that have shown that interactive teaching models yield better results compared to other teaching methods, especially in the field of anatomy (Yammine & Violato, 2015). Although, more importantly I feel there is potential for this project to be used outside of a college setting. I believe there are applications in doctors offices and other underprivileged areas and countries. This model was relatively cheap to make and with modern manufacturing this device can be easily mass produced for learning benefits across the world.

Conclusion

The development of this anatomically accurate teaching model for human eye movement represents a successful integration of biomedical engineering principles, educational design, and neuroanatomical knowledge. By creating a physical representation of the complex oculomotor system, our team has produced a valuable educational tool that transforms abstract neurological concepts into observable mechanical relationships.

The completed model effectively demonstrates the intricate coordination between ocular muscles and neural pathways through both its LED neurological display and its mechanical representation of eye movements. Despite some limitations due to budget constraints and manufacturing methods, the model successfully fulfills its primary educational purpose by visualizing saccades, smooth pursuit, and vergence movements, while accurately representing both healthy and damaged functions.

Physical teaching models like this one offer significant educational advantages over traditional learning methods. As demonstrated by research, these models allow students to interact directly with complex systems in a simplified, three-dimensional format, enhancing comprehension and retention of difficult concepts. The ability to visualize sequential neural activation alongside the resulting physical movements creates a powerful connection between theory and application.

This project not only serves as an educational resource for Colorado State University's neuroscience curriculum but also demonstrates the potential for similar teaching tools to be implemented in various educational and clinical settings worldwide. The relatively low production cost and reproducibility of the model suggest possibilities for broader distribution, particularly in resource-limited environments. Through this work, we have created a tool that makes complex neuroanatomical concepts more accessible and understandable, ultimately contributing to improved education in neuroscience and related fields.

References

Cleveland Clinic medical. (2025, April 2). *What your eye muscles do for you*. Cleveland Clinic. https://my.clevelandclinic.org/health/body/eye-muscles

Coiner, B., Pan, H., Bennett, M. L., Bodien, Y. G., Iyer, S., O’Neil-Pirozzi, T. M., Leung, L., Giacino, J. T., & Stern, E. (2019, August 12). *Functional neuroanatomy of the Human Eye Movement Network: A review and Atlas - Brain Structure and function*. SpringerLink. https://link.springer.com/article/10.1007/s00429-019-01932-7

Eye Movement Control. Eye Movement Control - an overview | ScienceDirect Topics. (n.d.). https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biolgy/eye-movement-control

Lennerstrand, G. (2007, October 18). *Strabismus and eye muscle function*. Wiley Online Library | Scientific Research Articles, journals, … http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0609.2007.00853.x/abstract

Physical Model. Physical Model - an overview | ScienceDirect Topics. (n.d.). https://www.sciencedirect.com/topics/engineering/physical-model#:~:text=One20of%20the%20main%20benefits,parts%20of%20the%20particular%20system.

Purves, D. (1970a, January 1). *The actions and innervation of extraocular muscles*. Neuroscience. 2nd edition. https://www.ncbi.nlm.nih.gov/books/NBK10793/#:~:text=Three%20antagonisti%20pairs%20of%20muscles,rectus%20and%20superior%20oblique%20muscles.

Purves, D. (1970b, January 1). *Types of eye movements and their functions*. Neuroscience. 2nd edition. https://www.ncbi.nlm.nih.gov/books/NBK10991/

Themes, U. (2019, January 23). *Neural control of Eye Movements*. Ento Key. https://entokey.com/neural-control-of-eye-movements-2/#:~:text=The%20oculootor%20nucleus%20innervates%20the,called%20the%20Edinger%E2%80%93estphal%20nucleus.

Yammine, K., & Violato, C. (2015, October 12). *The effectiveness of physical models in teaching anatomy: A meta-analysis of comparative studies - advances in Health Sciences Education*. SpringerLink. https://link.springer.com/article/10.1007/s10459-015-9644-7