Final Report

Robot to Mimic the Horizontal Fast Eye Movement System

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Abstract

The oculomotor system is comprised of the eye ball, the optic nerve and six muscles that control movement torsionally, vertically, and horizontally. By extending and contracting these muscles, the oculomotor system can produce five different types of motions. Our model will be mimicking the Saccade and the two muscles in the oculomotor system which produce this horizontal movement; the lateral and medial rectus. A Saccade can be defined as a fast eye movement which involves quickly moving the eyes from one target to another without concern for the information passing through the retina during the movement. The Saccade is a conjugate movement meaning that the two eyes are ‘yoked’ together, and receive equal and simultaneous innervation in accordance to Hering’s Law.

With this understanding of the physiology of the eye, it will be possible to model this system. Linear actuators will be used to produce the same type of movement induced by the abduction/adduction of the lateral and medial rectus muscles. Springs and dash-pots will be used to smooth the movement given by the linear actuators. Electrical input for the linear actuators will be attenuated accordingly using software. This input will be used to mimic the nerve impulses given off by the brain in response to visual stimulus. Modeling this, we will utilize an equation that uses the input of the required rotation angle as well as constants specific to our mechanical components to alter equation parameters, resulting in a concise, optimized, and accurate rotation.

1 Introduction

1.1 Background

Dr. John Enderle is an esteemed professor at the University of Connecticut. A major focal point of his research expertise is the physiological modeling of human systems. Of these systems, Dr. Enderle’s research on eye movement bio-mechanics and properties represents the cutting edge of our understanding of the inherent complexities of eye movement. His paper, “A Third Order Linear Saccade Model” [1], details in great depth the physiological properties of the horizontal eye movement system of the saccade. Dr. Enderle has expressed the need for a robot that accurately and reliably mimics the Horizontal Fast Eye Movement System. The robotic eyes will be required to recognize a light stimulus within a +/- 15 degree field of vision via a system comprised of a single USB camera. Upon the recognition of a stimulus, the system will rely on software to isolate the light stimulus, distinguish it from background noise, and compute the distance of light from the current centralized visual location. Once this is complete, the system will use this information in conjunction with relevant eye movement modeling data to rotate
the eyes to the appropriate viewing angles, so that the object is re-located to the center of the field of vision. This rotation must mimic the horizontal eye movement system as closely as possible.

To achieve this, the movement of the eyes will be driven by four linear actuators supplemented by dash-pots and springs, which will model the important viscoelastic properties of the eye musculature. These components will be used to fabricate the lateral and medial rectus, the muscles which supply the horizontal movement to the eyes. Like the human horizontal fast eye movement system, the robot will rotate as quickly as possible in a “fast jerk” motion until the desired location is reached. The system will not be required to imitate the usually associated saccade overshoot and subsequent visual correction behavior; that is to say that the eyes will cease movement the moment the object passes through center of the field of vision, and any overshoot correction mechanism will not have a requirement to be attuned to the exact human specifications.

1.2 Purpose

The purpose of this project is to construct a Horizontal Eye Movement Model which will embody the research Professor John Enderle has been compiling since the 1980’s. Ultimately, our eye model should represent the human horizontal eye movement system as closely as possible, and with acute accuracy in regards to both motion and simulated neural input response.

1.3 Previous Work Done

Professor John D. Enderle has been working on the oculomotor system since the 1980’s. Since that time, Professor Enderle has put forth many publications on this system. The first publication dealing with the movement of the human eyes comes from 1980, called the “Linear Homeomorphic Model for Human Movement” [2]. This paper outlines a model for the eye movement system, and more general neurological control systems, using an ideal spring.

Alex Korentis, a PhD candidate, is currently working on a three dimensional eye movement system which uses eight linear actuators to give the system mobility in three dimensions.

We will also be working in contact with another design team -- a team constructing a model of the circuits of the neurons in the human brain. Ideally, this type of circuit would mediate the inputs and outputs, solving the eye movement equations and then relaying directions to the actuators in a similar fashion to the human brain. The final product would be a combination of sensory and processing equipment very similar to that of the human system.

### 1.3.1 Products

There are currently no existing products that attempt to mimic the linear horizontal fast eye movement system. There is however, a superfast robotic camera that is being developed by a team of researchers, lead by Professor Heinz Ulbrich, at the Institute of Applied Mechanics at the Technische Universität München [8]. The team has been working on a superfast camera orientation system that can reproduce the human gaze and can move over 2500 degrees per second. In conjunction with their project partners from the Chair for Clinical Neuroscience, Ludwig-Maximilians Universität München, Dr. Erich Schneider, and Professor Thomas Brand, the Munich team, which is supported in part by the CoTeSys Cluster, are developing a system to overcome certain limitations given by the eye-tracking software and head-mounting cameras. This project is similar to our project only in the sense that they can control the movement of the eyes at or exceeding the speed specifications of human eyes. Since our project is very unique, there are no other products that aim at achieving the same eye system.

### 1.3.2 Patents Search Results

There is currently a patent on the NiTi shape memory alloys that we will be using to drive the movement of the robot’s eyes. The patent is covered by the US Patent Numbers 6,326,707; 6,574,958; 6,762,515; 6,832,477; 6,928,812; 7,021,055; 7,256,518; 2,391,746, Australia Patent Number 772,107, China Patent Number 00811428.5, European Patent Number 1,203,156, Hong Kong Patent Number 104736 and Taiwan Patent number 184166/91102769.
1.4 Map of Report

Below are details required to understand the past, present, and future of this project as well as the numerous redesign iterations needed to stress the evolving nature of such a project. Under “Project Design” one can find these specific details regarding the evolution of our project, it’s capabilities in regards to each of its subunits and a full description of the prototype design. Section 3 contains a detailed description of our financial and technological constraints. The following section addresses our safety concerns, which need to be acknowledged by any users of our model or anyone reproducing technology detailed in this report. The following two sections (5 and 6) describe the applicability of the technology used in this project and the engineering practices/skills acquired in the construction of our robot. Furthermore, the following section details our budget for the completion of the project. Also listed are the individual member contributions as well the reference section and appendix.

2 Project Design

2.1 Introduction

The core objective of this project is to pursue the construction of a robot which will mimic the horizontal fast eye movement system. The challenges of this undertaking will be, firstly, to devise a mechanical system which can realize the same inherent quickness that is obtainable by the biological system, but to also target an object and reposition itself such that the target object will be aligned in the center of its field of vision.

In previous target acquisition methods, a binary image transform was going to be applied to an RGB image taken from the globe cameras in order to locate its next target move. In theory the centroid of the largest white pixel mass would yield the x and y coordinates required for the desired movement. In execution, there were several draw backs that were not anticipated.

![Figure 2: Previous Targeting Method](image-url)
In figure 2 above, the blue LED can be seen in the binary image transform. Unfortunately, every other bright object was also detected. This would yield inaccurate results. Subsequently, a color filtering application was developed which solves these initial issues.

Another prior design aspect which has ultimately been removed from the optimal design was the Bluetooth modules which were intended to transmit image data between the globe cameras and the computer. This design was determined unfeasible due to the size constraints of the globe itself.

Initially our method of actuation was going to be provided by PI piezo linear motors. These active state tension generator substitutes would have been optimal due to their compact size, virtually unlimited travel length, minuscule stepping increments and large peak velocity. Upon further investigation it was found that they would be much too expensive (~$11,000 W/Drivers) and thus eliminated from our optimal design, which is described in full below.

2.2 Optimal Design

2.2.1 Objective

As previously mentioned the goal of this design is to mimic Dr. Enderle’s Horizontal Fast Eye Movement System as closely as possible. In order to complete this, the robot will need to track a light stimulus with the utmost speed and precision. Each of the subunits described in the subsequent section will need to work seamlessly together to for this project to be successfully completed.

2.2.2 Subunits

2.2.2.1 Arduino Mega 2560 Microcontroller

The Arduino microcontroller is an open-source physical computing platform based on a simple i/o board and development environment that implements the Processing/Wiring language. A microcontroller will collect position data from the target acquisition stage via serial communication and relay the appropriate control input signal to the actuators to initiate movement. The arduino will also take the analog input values from the various linear potentiometer position sensors, which will be used to move the motors to the appropriate stroke and keep them there. The position sensors will also take data that will be used to determine the accuracy and speed of our mechanical system when compared to the data presented in Dr. Enderle’s published documents.

2.2.2.2 Light Emitting Diode (LED) Display
A programmed arduino uno will be used to randomize the order in which the LED’s will be lit. The display will be 32 inches long and placed every 5 degrees, or in 3.5 inch increments along the display length. Using the arduino’s IDE, a simple script to control voltage to the LED’s can be accomplished. 10 bar-segment LED’s will be used and mounted in a wood board. A pane of plexiglass will be painted with the exception of where the LED’s are located and used to cover the front of the display board. This will be both ascetically pleasing and also help to facilitate the image processing feature.

2.2.2.3 Camera

The camera that is to be incorporated into our design is the 8 mega pixel Mini USB cameras. These cameras are advantageous specifically because of their size, with the camera being a mere 15 mm in diameter. The cameras take 320x240 pixel images at 30 frames/second. They are nearly compatible with the globe design. The one drawback is that the circuit board is roughly one inch long. The components will have to be re-purposed and a design will be constructed in NI Multisim, and ordered through Ultiboard. Using SnoopyPro, a free USB sniffer under the GNU general public licence, will be used to capture the device driver communication with the camera hardware.

2.2.2.4 OpenCV

OpenCV provides a wide range of programmable functions for doing image transformation. OpenCV is available in C, C++, and has Python binding support capability. OpenCV will be utilized to acquire targets, and from the data, determine positioning information. To accomplish this, a Hue Saturation Value Transform, or HSV for short, will be applied using openCV’s built in convert color function. HSV is a transform alters the way color is represented. Hue can be described as pure colors, such as green or blue. Value changes how light or dark and image is, or figuratively, it’s responsible for determining the difference between navy blue and baby blue. The Saturation is a representation of color in an image. A completely desaturated color would be considered a part of the gray scale. Applying a HSV
transform is advantageous for filtering because only one color value needs to be targeted, not a mixture of red, green, and blue values. An upper and lower threshold will then be applied to the image to filter out all colors that don’t fall between the appropriate threshold parameters. The result is a binary image (black and white) where white depicts any color which falls into the applied threshold, and black represents every color that does not. From this point, the centroid of the white pixel mass may be calculated and the x-y position can be found.

### 2.2.2.5 MigaOne-10 Motors

In order to model the contraction of the linear and medial rectus muscle’s, a fast and accurate linear actuator must be employed. The MigaOne-10 provides a suitable fit for this project, and despite a few drawbacks, has many unique properties that can utilized. The MigaOne-10 linear actuator works on the properties of the NiTi shape memory alloy. Shape memory alloys change shape based on temperature. If the temperature of the alloy passes a certain lower threshold, the wire then change crystalline structure from an austenite to martensite and vice versa. This shape memory alloy is used as a piece of resistive wire in a closed circuit. This resistor will naturally dissipate heat into the atmosphere and the input voltage and current will follow the equation known as Ohm’s Law.

\[
\text{Voltage} = \text{Current} \times \text{Resistance} \quad [1] \text{Ohm’s Law}
\]

With this relationship in mind and given that in increase voltage will result in an increase in current and heat, it becomes apparent that a driver input can be used to directly tune the actuation speed and distance.
The horizontal saccade completes a 15 degree rotation in a mere 70ms, from the beginning of muscle contraction to the end of eye rotation and in an astounding 40ms for less than 5 degrees of rotation. Use of the MigaOne motor provides an ideal way to model this, since actuation of the MigaOne motors covers a .325” stroke in as little as 38ms when a voltage of 32 V is applied. The motor is capable of outputting 8.82 N of force, which is beyond sufficient for our needs. Not only do these motors comply with the technical specifications of the project, but they are also very small and lightweight (weight of .7 ounces and dimensions comparable to a credit card).

2.2.2.6 Voigt Elements

Fast actuation alone is not enough to correctly and accurately model the movement of the human eye. To simply connect the linear actuators tangentially to the globes would completely ignore the unique properties of eye musculature. In order to ensure that our model exactly follows Dr. Enderle’s horizontal fast eye movement system, we based our design on the diagram above see in figure 5. Rotation of the eye involves the agonist/antagonist muscles (shown in red). The agonist muscle will engage the active state tension generator to provide a “contraction force”. What makes these viscoelastic components so important is that the only thing resisting this “fast as possible” muscle twitch are the natural elastic and viscous properties of the antagonist muscle. In addition, the active state tension generator in the antagonist must resolve itself from the system as to not resist contraction. Once the target of the system is in the
center of the field of vision, the agonist will no longer offer tension (that is, to stop the “contraction”) and the antagonist muscle will fire as a means of slowing down the eye and reducing overshoot.

The active state tension generator lies in parallel with a dash-pot and a spring. These act as modifiers to the input motion, but in a more realistic sense, model the elasticity and viscosity of the rectus musculature. A spring acts as a force on the system that resists compression/extension (the force is proportional to the position) and models the natural “stretchiness” of the muscle. A dash-pot acts as a force on the system that resists compression and extension based on velocity (thus it is proportional to the system velocity) and models the “viscosity” associated with living muscle tissue. Knowing the associated equation for force based on mass and acceleration and that the actuation with the input of these parameters represent the force, we can draw the following equation, using \( x \) for position and \( \frac{dx}{dt} \) for velocity.

\[
F = -kx + -b \frac{dx}{dt} \quad [2] \text{Force Equation}
\]

When it comes to modeling the coefficients (\( k \)'s for spring constants and \( b \)'s for damping constants), springs can be easily implemented, since they are both widely available for custom order and come in an array of sizes with varying elasticity. They nearly need to be selected based on resting length as well as coefficient \( k \). They should only offer extension resistance and compression resistance that best resolves back to the center of vision.

![Figure 6: Spring Modeling](image)

Modeling the dash-pot, on the other hand, requires a unique design solution. As stated above, dash-pots are velocity attenuating models, that exert resistive force only as the position of its stroke changes, and that force linearly reacts to the velocity observed by the object in question. The proposed solution involves using off-the-shelf miniature “double acting”
pneumatic cylinders. “Double acting” implies that the cylinder is not spring loaded, and its moves in two directions evenly. Venting holes on either side of the piston allow the cylinder to vent in both directions. We plan to add two adjustable “flow-out” meters to the vents on either side of the piston, which will attenuate the air flow out of either end of the piston (see figure 7 below).

![Figure 7: Dashpot Model](image)

As air forcibly escapes the vents on either side of the pneumatic cylinder, our stroke is resisted comparable to how tightly the flow-out meters close the pneumatic vents. Since these are adjustable, we should be able to mimic the coefficients as observed in the human system with little error. Our definition of dash-pot is upheld as well, since no force acts on the system when the stroke is not moving.

### 2.2.2.7 Rail System

Another hurdle in the successful implementation of viscoelastic components is the translation of energy from one component to the next. Given the small scale of our model, many considerations must be made regarding attachment of our springs and dash-pots in series.

![Figure 8: Component Stages](image)
As one can see from figure 8 above, there are two distinct stages for each viscoelastic attenuation. The first involves a spring and a dash-pot in parallel with the actuator, and the second involves the attachment of this first component to another set of just spring and dash-pot in parallel. As a force is applied to the active state tension generator, the actuation will be affected by $B_1$ and $K_{lt}$, and the resultant of that motion will be affected by $B_2$ and $K_{se}$.

Our solution was the design of a “linear rail system”, which involves using linear blocks of Ultra-high-molecular-weight polyethylene (UHMWPE) sliding along a steel track. Linear blocks will provide places for the attachment of our components, and they can only move in one dimension (sliding up and down the track). They will prove to linearize the forces exerted by our components and active state tension generator because of this uni-dimensional constraint, and no matter where the attachment of the spring and dash-pot components are on our design, all torque will be resolved to linear motion, since these blocks cannot twist along their track.

Another advantage of this solution is that the energy is transferred from one stage to the next with only minimal force lost. Each linear block represents another stage, and the forces exerted on either end of the block will affect its overall motion. The final linear block in each stage (there are two for the movement of the eyes and one required for the modeling of the superior/inferior rectus) will attach one side of the block to the eye.

The main advantage to this design is in the friction between the linear blocks and the steel track, which will yield a coefficient of 0.08. This coefficient of friction is about two times that of the lowest coefficient between any two materials available, which is teflon-teflon and
that which has a coefficient of 0.04. Since the density of UHMWPE is roughly half that of teflon the difference in weight will make the coefficient variability negligible and the results very similar.

2.2.2.8 Simulink and MATLAB Simulations

The equations outlined in Dr. Enderle’s “A 3rd-Order Linear Saccade Model” are what calculate the correct position, velocity and acceleration of the eye as it moves. The main equation used is shown below:

\[ \delta \left( B_2 \left( \dot{F}_{ag} - \dot{F}_{ant} \right) + K_{se} \left( F_{ag} - F_{ant} \right) \right) = \ddot{\theta} + P_2 \dot{\theta} + P_1 \dot{\theta} + P_0 \theta \]

These parameters are based on a range of constant and variable inputs specific to the system. Because this is a system modeling the human eye, many constant values are intrinsic to the human body and therefore will not change based on the system. These constants include the tau and cap T constants, which represent time constants for the triggering of different types of forces and movements within the neural or other inputs. These values were determined by experimental lab data and will not change based on the system. Other variables, such as the ‘f’ variables, actually are dependent upon the elements from the oculomotor plant, and must be determined for our specific system. This will likely prove a challenging problem to solve, as the values of these variables are completely unknown without the accurate testing of the elements in the system. These include every spring and dashpot from the oculomotor plant, and their characteristics of movement on the linear track under a controlled force.

A Simulink block diagram has been created, once again based on the one provided from Dr. Enderle’s “A 3rd-Order Linear Saccade Model”, to model the eye movement equations. This version of the model is much preferred to the raw equations plugged into MATLAB because of its accuracy and visual ease. The Simulink program provides a method of solving for the important agonist and antagonist active state tension signals for which we will relay to our two motors. These are the ‘Fag and Fant’ variables from the above equation, and are the only elements of the system that we have control over once all the mechanical elements are in place.

The diagram will also prove to be a powerful simulation tool to see just how accurately the system is functioning. We can determine what the position needs to be versus time based on the values we input into the program for the force constants. Then we can experimentally measure what our actual eye is giving us, and compare the two. The great thing is that we can compartmentalize the system just as we would the program so that we can debug the system at each step with ease. For example, if the Fant response is inaccurate within the actual system,
we can compare each of the inputs with it’s Simulink representation and determine the source of the problem immediately.

2.2.2.9 Globes (Density and its affect to moment of inertia) (Attachment of Kevlar string)

The manufactured globes will need to be the size of the human eyeball, or 24mm in diameter. Having a human eye ball diameter has several advantages. Dr. Enderle’s equations for movement used physiological dimensions. In order to accurately create a physical representation of his model, the team wanted to keep to scale as much as possible. In conjunction with this motivation, if the globes were any larger, the equations for movement and velocity would need to be scaled accordingly. Any further increases in velocity would not be supported by the MigaOne motors.

The globes will be fabricated out of High-Density polyethylene. This will give the eyes a very light mass which will allow for easy actuation. The globes will also have two sleeve bearings, one on the top and bottom, through which the aluminum rods will pass through the centroid. The bearings will minimize the friction during the rotation of the eyes.

2.2.2.10 Mount/Bearing/Stage

The base of the stage will be made out of aluminum which will provide a very strong and lightweight foundation. There will be a single aluminum rod extending vertically outward from the base which will pass through the bearing of which the globe is press fitted into.

2.3 Prototype

The eye robot incorporates both mechanical and electrical processes to simulate a biological system. Motors actuate, analogous to human muscle, to pull the eye a certain direction. Springs and dashpots simulate normal resistive force inside the eye musculature system to dampen velocity and elastically resist motion. The camera and corresponding data indicate to our arduino mega which saccade the eye will be required to perform next. Linear potentiometers tracking the motor actuation return data about the current location of motor stroke, which provides location correction feedback information to the Arduino Mega.
regulator circuit compares and controls the flow of current to each motor. Electrical energy is provided to the system by a BK Precision 1745 DC power supply. A detailed description of how to properly use the prototype is present in the owner’s manual [11].

3 Realistic Constraints

It should be noted that there are no social, or ethical constraints while pursuing this project, though there are several design constraints that must be considered. One of the major realistic constraints that arises when attempting to mimic the Horizontal Fast Eye Movement System is the absence of neural inputs. Since there is currently no perfect substitute for the mimicry of nerve impulses driving the movement of the eye, it becomes difficult to simulate the ideal system. This constraint is being addressed by another design team and in the near future will be compatible so that the circuitry of the neural network can be incorporate into our robot.

Given the size and specificity of the model, it is likely that the project will have limited compatibility, meaning the parts used will not necessarily be interchangeable with other models and the project may not be suited for large scale “tweaking” of design parameters.

Scaling of the model must also be considered. At the current design phase, the eye size is 1:1 with the average human eye size (24mm diameter). Despite this, other components, such as the actuators and the rails system which houses the viscoelastic components may incorporate unknown forces on our system. The linear block’s weights also need to be accounted for during our actuation. This deviation from homeomorphism may yield additional problems that cannot be predicted from observing the actual biological system.

The human eye and its processing mechanisms have proven to be an extraordinarily fast system. Modeling such a system with many devices in constant communication with each other will certainly accumulate some latency -- likely more than desired. A 15 degree saccade takes ~70ms to move from start to finish which is a very small window of operation. There are several bottle-necks that can be introduced to the system if the design is executed poorly. The largest constraint to the design is the rate of transfer. Although our original design considered using blue-tooth communication for wireless transfer between our eye’s cameras and our microcontroller, the size of blue-tooth modules and transfer rate constraints made the incorporation of a blue-tooth module a problem.

Because of these file transfer and processing constrains, we consider that our eye needs only one picture to begin movement: the picture of the light stimulus before rotation. By calculating the degrees needed to turn for each eye from this one image, each eye will have to move a specified saccade “blind”, in that it does not process the approach of the light stimulus to the center of the field of vision as the eyes are rotating. The motion will stop when the
actuators move the appropriate distance as predetermined for the corresponding saccade, and overshoot/undershoot will have to be addressed after experimentally determining the magnitude of error.

Budget restraints are also a practical hindrance, as this severely narrows the number of linear actuators on the market that would fit our specifications. Although the MigaOne motors were selected as optimal, many motors (including piezoelectric motors) were overlooked because of price (See [9] and [10]). These motors moved either faster than the MigaOne motors, had a release mechanism that allowed the actuator to release itself from the system, which is an attribute we will need account for with a modified use of the MigaOne SMA motor.

The MigaOne motor encompasses all the qualities that are required to make the actuation successful. It provides an adequate velocity for the movement and the stroke length of the motors are large enough to move the eyes from 15 degrees to negative 15 degrees. Most importantly the MigaOne is cost effective, unlike most motors that are available. That being said, the MigaOne does have some drawbacks. Because it is a memory shape alloy, when voltage is not being supplied to it relaxes back to its original shape. The relaxation time of these alloys fall between 3 to 5 seconds. This is going to increase the waiting period between movements in order to allow for the alloy to return to a steady state.

Lastly, recent team developments in the design of a clutch mechanism have perhaps provided us some performance constraints. Since the MigaOne motors have a long relaxation time (as described above), back-driving them at the same speed as actuation is not possible. As a team we have discussed alternatives to fix this constraint and a few options arose. One way of engaging a clutch mechanism involved only engaging in a saccade from a “0 degree” position, meaning that each saccade would originate from a central position (such as each eye simply looking straight ahead) and, after the saccade has been performed, the system would reset itself to that position. This clutch mechanism involves utilizing the MigaOne motors in a “one-way” configuration that would only exert force on the system during contraction. This system would result in the system being unable to originate a saccade form the peripheral, but it is still in the design process and will be explored in further detail as the project progresses.

4 Safety Issues (Add neodymium hazards)

Based on the optimal design above there are both electrical and mechanical dangers involved in our project, and it is of much importance that our team eliminate these dangers where possible and provide precautions where danger cannot be completely avoided.

The MigaOne linear actuators pose some minor safety issues. Firstly, these actuators and their associated drivers pose a shock hazard, with possible input voltage nearing 30V and current that may reach 10 Amps. Besides a shock hazard, the MigaOne linear actuator poses a burn/fire hazard. These motors operate off of the re-shaping of a NiTi shape memory alloy. A
A coiled piece of NiTi wire provides the actuation when a battery source applies voltage to the NiTi (acting as resistive wire), which dissipates heat. The wire needs to reach temperatures above 70 degrees Celsius to initiate the change in crystal structure conformation, which causes the actuation movement. By using the custom MADv5 drivers, overheating is prevented by inclusion of a heat sensitive limiter that kills power to the motor momentarily when a set stroke length is reached. Rigorous testing will be conducted to determine if extra cooling methods need to be utilized, such as fan or mineral oil cooling. Proper user protection, component shielding, and component fan cooling must be utilized to make sure that no possibility exists for burn injury as well as reduced chance of component damage and fire hazards.

The LED system housing also poses a low fire risk. LED illumination occurs without any sort of filament, and thus an LED operates at very low temperatures. Despite this, fans will be included in the LED system housing to prevent the LED circuitry or PIC from overheating, which can decrease the risk of component damage or fire hazard.

5 Impact of Engineering Solutions (AI)

The device detailed above represents a major step forward in physiological modeling. The human eye movement system is an evolutionarily optimized system and our understanding and replication of this system only helps to forward progress in both robotics as well as biological systems modeling. An anatomically correct and accurate model is of much use medically, as it provides a good benchmark for how biological systems should work in normal healthy individuals. Future plans for incorporating our model into a simulated “neural network” are in place, and the completion of such integration would result in not just providing an accurate biological benchmark, but also by increasing the parameters of the system. If the simulated neural network controlling eye movement is modeled anatomically, then it is possible that one could observe a benchmark for unique conditions and their effects on eye movement. For example, if a person has a particular disorder or finds themselves in a state where their cerebellum isn’t functioning correctly, altering parameters on the neural model could go as far as to show us how the physical eye responds, as this parameter change would correspond with altered input for our horizontal eye movement system.

These types of eye movement models have much room for future growth and improvement/optimization. The next logical step in modeling this system is to add the functionality of the superior inferior rectus, that is, to model the eye in its movement on more than just the horizontal plane. Functionality could even be further increased by modeling eye movements other than the saccade, such as tracking eye movements and viewing objects on the eye periphery. Perhaps the future will even yield a model that includes the neck and its role...
in the tracking of objects through eye’s field of vision. A good starting place for all of these future technologies though is rooted in our understanding and accurate modeling of the horizontal saccade. Using the same positional logic and the musculature modeling of our design could provide a jumping off point for these future technologies.

With the growing ease of implementation and shrinking cost of camera technologies, it is likely that our model represents at least a piece of the logical conclusion of motion camera capture technologies. The key is that our human eye movement system, already optimized by biological evolution, is able to make informed decisions and reactions based on the dynamic properties of a stimulus. It is apparent that the biological eye movement system is the real dominant technology in existence, and our mimicry could help make our technical world catch up in efficiency.

The medical world could also benefit from progress in this field. If, in the future, doctors were able to engineer a synthetic, implantable eye, a device like ours may not only just help in discovering relevant biological data for consideration during fabrication of the device, but also could provide insight on implementing an accurate synthetic musculature to suit that eye, or at least to serve as a benchmark for prototype testing.

6 Life-Long Learning

This project not only fosters our ability as a team to deliver a completed project based on a client’s need, it also very importantly tailors to our individual learning and development as emerging engineers. The concept of teamwork is vital to the success of a project, and good teamwork skills are immensely translatable, both inside and outside the engineering realms of research and industry. It has been a goal for members of the team to always be in communication with one another. In addition, each individual is accountable for specific aspects of the project, but it is of great concern that, as a team, we make sure that we help each other complete their aspect of the project; preventing one person from ever bearing the entirety of a component or aspect of the design. Another facet of general learning would be our ability to work on a timeline and produce a deliverable that reflects a product that is not necessarily concrete in how it can be executed. This mixture of creativity and constraint develops our team’s working sensibility and has been promoting organizational skills for long term projects.

As is the reason for senior design projects, many industry skills can be learned or honed in the design and build process of a project such as this. We have been learning viable job skills from simple component soldering to working with an industry drafting standard such as Solidworks. Also, few scholarly projects rely on a team to “start from scratch” on a design, and figuring a way to creatively implement your knowledge base to solve a problem is the basis for engineering as a practice.
Completion of a deliverable is only one aspect of this senior design project. Collecting both job and life skills as we work at this project is what one can really take away from the experience as a whole, and these skills will provide the foundation for the upholding of future engineering excellence.

7  Budget

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8 Team Member Contributions

Although an overall team effort was favorable for larger tasks and overall design and build of the robot, specific subsections of the project were found to be easier completed as individuals such as actuation, target acquisition, viscoelastic mechanics, and system modeling. This allows us to individually specialize in a component, and not only be held accountable for subsystem performance, but also to become experts on the finer details within a facet of the project. This environment allows us to constantly teach each other about aspects of the project we need to consider as a whole.

The movement of Dr. Enderle’s 3rd Order Linear Saccade Model is provided by the active state tension generators in the oculomotor plant model. We will be using NiTi shape memory alloys to provide the mobility of the eyes. Since the MigaOne-10 motor has such a small stroke length, a simple lever system will be used to increase this. Although this will decrease the force the actuators provide on the system, it is not an issue since they currently provide a force roughly five and a half times that of the human eye.

In a saccadic movement, the eye moves rapidly from one point of fixation to another. In order to emulate this, Drew has devised a 30” display housing 9 LEDs. The LEDs are lit off at random using a PIC microcontroller. Once the LED is lit, Ian has written some code to do target acquisition using HSV color filtering. The code will pick up on the blue LED and then calculate its x-y position.

In order for the system to correctly model the natural movement of the eye, viscoelastic components must be designed into the movement system. Drew has been working specifically on modeling this complex movement system by design of the “linear rails” system as well as the selection/customization of both springs and dash-pot options. The system’s implementation requires intuitive solutions that allow the actuator to interface eyes while retaining the overall goal of homeomorphism.

Testing each component of the device for precision in accordance with Dr. Enderle’s horizontal linear eye movement system will prove to be an essential step to an accurate model. Therefore, Matt has constructed the Simulink block diagram representation of the whole system for the purposes of experimentation and testing. Focus can be made on individual sections of the program, or even individual blocks, in order to make sure that the device mimics the linear system accurately at each step.

8.1 Tyler Harrington - Bio-informatics track

Contributions
- Actuation Control Methods
- Helped interface the arduino code with the PYTHON code
- Assisted in constructing Mechanical Design
○ Purchase Requests
○ Update of Website

8.2 Ian Rogers - Biochemistry track

Contributions
○ Wrote PYTHON code for image filtering
○ Developed code for the calculation of x-y position
○ Constructed interactive communication between computer and micro-controller

8.3 Andrew Bligh - Bio-informatics track

Contributions
○ Viscoelastic System Modeling & Rails system
○ LED display system Fabrication
○ Solidworks drawings
○ Eye Mount Design

8.4 Matthew Morra - Bioinstrumentation track

Contributions
○ Simulink block diagram for Dr. Enderle’s eye model
○ Flexible MATLAB workspace for eye movement equations
○ Simulation of eye muscles for different degrees of saccade
○ Power Supply Circuit design

9 Conclusion

This project embodies the mathematical models outlined by John D. Enderle in his work on the fast eye movement system, [1], [3-7], in a physical demonstration that will aid anyone interested in these models by serving as a means to understand them both visually and conceptually. The system should appear to mimic the human fast eye movement system. When the project is interfaced with the neural circuit provided from the other design group, the project will further imitate the human sensory system. With the main goal of homeomorphism, and with the human system being studied in detail, this project will execute a well-established build plan to fabricate and implement the fruits of a rigorous design phase, resulting in an accurate model of the human linear saccade.
10 References


11 Acknowledgements

Dr. John D. Enderle | Client – Uconn BME Professor
Alex Korentis | UConn PhD Student – QCI Engineering
Marek Wartenberg | BME Senior Design Advising
Mark Gummin | Miga Motor Company
Peter Glaude & Serge Doyon | UConn Machine Shop Engineers
Dr. Richard Jones| UConn Physics Professor
12 Appendix

12.1 Updated Specifications

Physical:  

Type of material:
- Eye case – HDPE
- Main support chassis – Aluminum
- Sleeve bearing – Steel
- Linear Blocks – UHMWPE
- Rails - Steel

Mechanical:

Size:
- Plastic Globe: 24mm radius sphere
- Camera: 10mm x 10mm x 7mm
- MigaOne SMA motor: 71 x 33 x 2.5mm
- Base Back Plate: 6” x 4” x .25”
- Outer Side Mounting Plate: 8” x 4” x .25”
- Inner Side Mounting Plates: 8” x 4” x .50”
- Bottom Base Plate: 6” x 10” x .25

Weight:
- MigaOne SMA motor: 0.45 ounces (12.8 grams)

Max eye rotation velocity (eye): 700 degrees/sec
Max eye rotation acceleration (eye): 60000 degrees/sec^2
Actuator speed: 278mm/sec (model eye r = 24mm)
Actuator acceleration: 22000mm/sec^2 (model eye r = 24mm)
LED change: Every 3-5 sec

Electrical:

Camera:
- 5V
• 30 fps
• 330x240 pixel resolution

*MigaOne SMA motor:*
• 0-30V supply
• 278mm/sec peak velocity

*Arduino Uno:*
• 7-12V supply, 5V operating
• 40mA per I/O pin

**Environmental:**

*Storage Temperature:* 0 – 150 °F  
*Operating Temperature:* 40 – 110 °F  
*Operating Environment:* Avoid water contact. Avoid foggy or smoky environments to allow normal operation of camera.

**Software:**

*Software Interfaces:*
  OpenCV -- Open source language for visual processing aspect  

*Hardware Interfaces:*
  Arduino takes position information from the computer, and using the fast eye movement linear model with linear potentiometer feedback, relays movement inputs to the actuators, which rotate the eye.

*Features:*
• Frictionless horizontal movement of human eye model.
• JPEG camera senses light intensity of an LED and relays information to microcontroller.
• Highly precise actuation based on fast eye movement linear model.

*Computer Requirements:* None

**Safety:**

Proper use is achieved through careful handling of product:
• Carry product by base, not eyes or 'head'
- Do not dangle device by cord

Maintenance:
- Always turn off device after use.
- Before use, clean the camera with a wet paper towel or piece of cloth.
- After prolonged use, dusting the LEDs may be necessary to ensure level of brightness.

12.2 Purchase Requests

PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB

Instructions: Students are to fill out boxed areas with white background

Each Vendor will require a different purchase requisition

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Lab Admin only:
- FRS
- Student Initial Budget
- Student Current Budget
- Project Sponsor

Comments

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Yes or No

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Address: http://www.sparkfun.com/

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Contact Name: N/A

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Authorization:
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Biomedical Engineering
U-2247, 286 Glenbrook Road
Storrs, CT 06269-2247

**Attr:**
Tyler Harrington

**Project Name:**
Eye Robot

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#### ONLY CINE COMPANY PER REQUISITION

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**Address:**

[www.tmart.com](http://www.tmart.com)

**Phone:** Na

**Contact Name:** Na

**Vendor Accepts Purchase Orders?**

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**Shipping**

**Total:** $11.63

**Authorization:**

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28 | Page
### 12.3 Reader Information

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**PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB**

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<td>Total Expense</td>
<td>$236.78</td>
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</tbody>
</table>

**Student Name:** Tyler Harrington

**Ship to:**
- University of Connecticut
- Biomedical Engineering
- U-2247, 260 Glenbrook Road
- Storrs, CT 06269-2247

**Attr.:**
- Tyler Harrington

**Project Name:** Eye Robot

**ONLY ONE COMPANY PER REQUISITION**

<table>
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<tr>
<th>Catalog #</th>
<th>Description</th>
<th>Unit</th>
<th>QTY</th>
<th>Unit Price</th>
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**Comments:**

**Price Quote:**

**File Name:**

**Vendor:** Automation Direct.com

**Address:**

**Phone:** N/A

**Contact Name:** N/A

**Vendor Accepts Purchase Orders?** Yes

**Shipping:** $0.74

**Total:** $236.78

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**Authorization:**

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