Eye Tracker Robot:
Test Rig with Integrated Neck

Sponsored by:

Microsoft Corporation
Redmond, WA 98052

Brittney Downing, Carson Kreager, Max Larsen, Kaitlyn Lewis, Bennett Moore

Department of Mechanical and Materials Engineering
Washington State University
Pullman, WA 99163

Executive Summary

The first goal of our project was to build and deliver by March 1st, a replica robot based on the original one designed during the fall semester of 2020. The second goal was to design a neck that could be retrofit onto the robot to add an additional three degrees of motion and allow for more in-depth eye tracker testing. For our neck retrofit, the two designs that we considered were a 3 degree of motion (DOM) Stewart platform, and a spring-cable neck design. After consideration of both, the spring-cable neck design was chosen as it would be shorter and more stable than a Stewart platform. After going through multiple design iterations, we finalized a design that offered even more flexibility than a human neck and could easily be integrated into existing robots. Electrically many improvements and modifications were made, including but not limited to, implementing a custom PCB, adding additional TB6600 micro-stepper controllers, and improving cable management by increasing the electrical box size. Using transformation matrices to calculate the desired cable lengths, the stepper motors can tighten and loosen the cables to achieve the desired pitch and roll.

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Introduction

This document outlines the goals and requirements for the completion of the eye tracker testing prototype. Eye trackers are used by people living with ALS or other neuro-physical disorders. With multiple eye tracker manufacturers and their inherently different designs, an eye tracker testing prototype is a necessity to establish an eye tracking quality industry standard.

The first goal of this project was to create a replica of the eye tracker testing robot to be delivered to Microsoft's Redmond campus. Each of the two teams made a replica rig to get a total of three robots. Some changes were made to the robot such as adding a buck converter to allow the Arduino to be powered internally and changing the base box from wooden 2x6 to 8020 aluminum. These changes were based on issues identified in the previous semesters design during our replica construction process. As well as creating two more robots, the original Fall 2020 robot was also upgraded to use the same hardware as the spring 2021 replica robots, to then give three identical robots. This ensured a smooth integration of our hardware and software changes onto all robots and will make future work on these rigs much easier.

Our second goal was to create a neck upgrade for the Fall 2020 baseline testing rig to aid in the realism of the eye tracker testing as it relates to real-life patients. Our goal was to design a neck that is capable of around eighty percent of what an actual human neck can do and deliver a retrofit kit to Microsoft so they can incorporate this newly designed system into their robot. It was imperative that the new neck system could operate around three degrees of freedom to simulate neck muscle atrophy and Dropped Head Syndrome, which is a common result of living with ALS. The results from this neck upgrade to the baseline testing rig, and the data it provides will allow for the improvement of eye trackers. This is important because customers will have access to eye trackers that are more reliable for unique costumer conditions. Our neck upgrade for the baseline testing rig will allow us to test eye trackers when the head is not perfectly straight on.

Results and Discussion

We considered two different neck designs when beginning our prototyping phase. One neck we were considering was a 3 degree of motion (DOM) Stewart platform, and the other was a spring and cable neck design. The Stewart platform was considered as it is a well-known design that is used in hundreds of different applications, especially in the aerospace industry for various simulators. Additionally, our concept would allow for up to thirty degrees of rotation in any direction. There was however concern with this design as u-joints tend to get stuck at their angular extremes and the coding required for this design would be very complex. The spring and cable neck design was also considered due to its increased flexibility over the Stewart platform, as well as its compact and human like design. We decided to use the spring and cable design in the end because it would be more stable than the Stewart platform, and the issue with the u-joints was nonexistent with this design. There are still issues that we are worried about with this spring cable neck design.

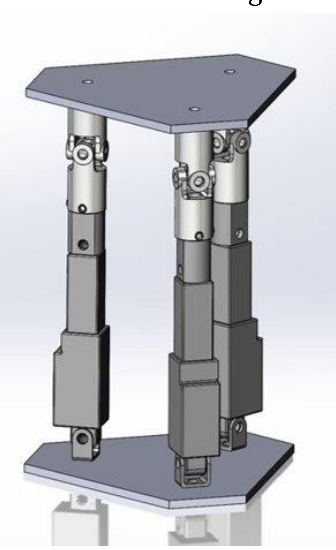

Figure 1-3 DOM Stewart Platform

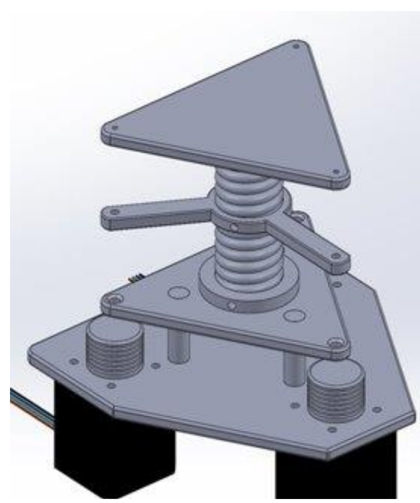

Figure 2-Spring and Cable Design

For one, we do not know how well this spring will perform over time and after many uses. We believe that the spring could potentially plastically deform causing the neck to become inaccurate to the point that it could not be used and would need to be replaced. We are also worried about deformation in the cables connecting the stepper motors to the actuating platform. These cables could be stretched out over time such that they may eventually not be able to hold the load of the neck and will break.

After deciding to use the spring and cable design, the next step was to identify issues with our first iteration. None of our original designs took into consideration how the yaw should be incorporated into the neck. We decided to use belt driven timing pulleys that use a servo to control the yaw. The entire neck mechanism is mounted on top of the yaw mechanism such that the entire neck rotates. Additionally, our spring and cable design needed to be adjusted such that the rotational axis of the spindle attached to the stepper motors was perpendicular to the cable rather than parallel. These were the major changes from our initial design to our final design. However, many small, functional improvements were also made to the design. These include such things as the use of an incorporated z-bar structure into the neck for the steppers, a turntable for the yaw as opposed to the original slew bearing, and an integrated spring end for the bottom and top plates. These changes along with our final design are shown below.

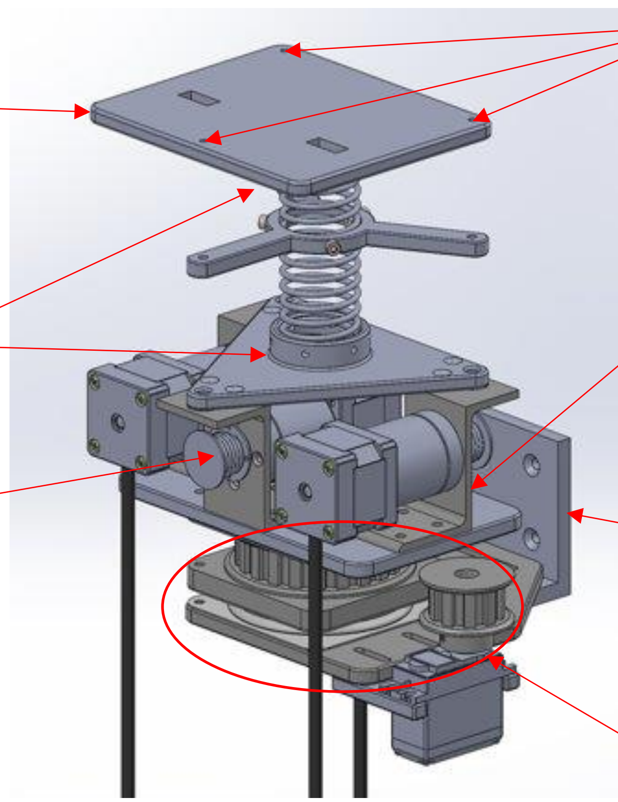

Figure 3-Final Neck Design

Our final neck design made use of three NEMA 14 stepper motors with universal gearboxes, as well as a 270 degree, 20kg-cm servo motor. Where the servo motor controls the yaw rotation of the neck using timing pulleys and a belt, the three stepper motors control the pitch and roll of the neck. Each stepper motor has a spindle that rotates to allow tightening or loosening of a Kevlar line at each of three points on the top spring plate. By combining the rotation of each of these stepper motors, we can achieve any combination of pitch and roll of our neck platform. Upon adding in the servo-controlled yaw system, it becomes possible to achieve any combination of pitch, roll, and yaw like what you would have in a human neck.

To manufacture this, all standard hardware like the motors, timing pulleys, turntable, screws etc. were ordered and are reflected in our bill of materials. Due to the required stiffness of the neck mechanisms, and strength needed to support the neck's weight, it was decided that all plates except for the top and bottom spring plates should be machined out of a quarter inch aluminum plate. The mounting bracket was made form a standard ninety-degree extrusion, and the z-bar stepper mounting brackets were cut and machined from an aluminum z-bar extrusion. All other components like the spindles, spring plates, and various mounts were 3D printed using a standard FDM style 3D printer.

Coinciding to the mechanical aspect of this project was an electrical element. The original Fall 2020 robot had a few electrical troubles that needed to be addressed. One enhancement was a custom-made PCB board that was requested by Microsoft to help organize wiring and allow for a more reliable wire connection to the Arduino. The Fall 2020 team had plugged in terminal blocks into the Arduino itself, but they kept popping out on their own and did not make a solid connection which made the robot unreliable. Another feature the previous Fall 2020 team attempted was to internally power the Arduino Mega/PCB by utilizing a separate 5-volt power supply. A separate power supply was used because the 24-volt power supply was too powerful. Unfortunately, this did not work and to combat this issue the Spring 2021 teams decided to run power from the 24-volt power supply to the PCB but have a buck converter in-between to scale down the voltage to the 5 volts that was needed. This enhancement also allowed for the 5-volt power supply to be removed from the robot completely. Another improvement that was made was adding a buck converter between the 24-volt power supply and the eye servos. The Fall 2020 robot had some eye servo twitching when we got it and that made parallaxing extremely hard. The correction for this was simple, all that was required was a 7-volt buck converter that helped damp any noise in the power that the servos were receiving.

Besides just fixing problems that the Fall 2020 robot had when received at the beginning of the semester, electrical modifications had to be made to accommodate the new neck components. Our team ended up making the electrical box 6 inches wider than the original Fall 2020 robot had. This was necessary to not only fit the two new buck converters, but also to fit the 3 additional TB6600 micro-stepping controllers that control the pitch and roll of the neck. Another new component added was an LCD screen that allows the user to interact with the neck without having to constantly update the code. Using the LCD screen, we also can see the angle at which the neck is located. To accomplish this an IMU was installed to give real time angle feedback of the neck location at any point in time.

Throughout the Spring 2021 semester, our team went through three iterations of electrical box layout before deciding on the final box design. But due to these iterations, wire management has improved significantly. Another cause for improved wire management was the use of stranded and bell core wire. The Fall 2020 team attempted to chain together a lot of premade jumper wires that are commonly used in mechatronics kits because they're convenient to plug into an Arduino board. But by doing this, the wire management looked unpleasing to the eye and was not as reliable as using normal stranded or bell core wire.

We went through 4 to 5 different methodologies for coding the neck. After talking with Dr. Swensen we decided to use transformation matrix math to calculate the transformation between the bottom and top plate. This in turn allowed us to calculate the desired cable length from a desired direction of tilt and amplitude of that tilt.

Conclusions and Future Work

We can conclude based on our work that our neck will offer a little over one hundred percent of the flexibility that a real human neck can achieve and should be sufficient to test eye trackers. However, there are several issues which should be addressed during any future work done on this robot. One issue we are seeing currently in the hardware is that our neck is too heavy for the robot. This applies a torsional load to the linear axes of the robot and causes inaccuracies in our actual neck position. Weight reduction in the neck and reinforcement in the axes would mitigate this issue and would allow the neck to be more positionally accurate.

For the electrical element of this project, the biggest recommendation would be to replace the current PCB with a new one. The current PCB has a few issues and really needs to be remade to fix some of the fundamental issues. The first issue with the current PCB is that it uses digital pin 50 for one of the neck TB6600 micro-stepping controllers. This didn't seem like a big problem until we realized that digital pin 50 is a special communication pin that always pulses high and low to attempt to find a communication signal. This means that no matter how we code it, that pin always pulses which makes the stepper motor pulse erratically. There is a coding fix to make that pin a regular digital pin, but every attempt made has not been successful. Plus, trying to fix a hardware problem with code is not the easier option.

Additionally, the traces on the PCB should be made larger. There have been a few servo related issues and it seems that maybe the traces on the PCB are to blame. So, if the PCB needs to be remade anyways to fix the digital pin 50 problem, then might as well just make the traces larger to prevent any possible overloading down the road. The last electrical improvement that is recommended would be to make the electrical box even bigger. The six TB6600 micro-stepper controllers are a bit cramped where they're currently placed and there is room to make the box bigger. Plus, A larger box would be nice for future teams in case they need to add electrical components or move things around.

The elegancy of the neck control movement needs to be improved. The most up to date code is very accurate in calculating the transformation matrix but has not had enough time to iron out all the control bugs. The gains and limits need to be tweaked for smoother control.