Cervical Proprioception Motion Analyzer

Detail Design Report

Department of Engineering and Physics
ENGR 4201. Senior Design
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Requirements Specifications

After conducting several interviews with multiple physical therapists, needs that were expressed included the following: The device needs to be easy to use. Physical therapists may not be as technologically savvy as the engineers who create the device, so it needs to output only the necessary information. Dr. Galindo expressed, “Typically, PTs will choose tests and measures based on convenience (i.e. if the ‘best’ evaluation tool takes me 30 minutes but a ‘good’ evaluation tool that is valid/reliable takes me only 10min, I will always chose the 10min version.)” They expressed that however the device operates, comfort is very important for the patient. Additionally, the device should not inhibit the patient’s motions. The device should provide objective, clear, and accurate data. Finally, the device needs to comply with all relevant legal and industry standards in order to be usable in a medical setting.

The time required to run a CPE test with the CervPro device will not exceed 10 minutes. This is double the time required to run the CPE test without the device. The proportion of therapists able to make a diagnosis exclusively using the device and within 40 seconds of completing the CPE test using the device shall be above 50%. Any device hardware will not inhibit the movement of the neck across an 80 degree RoM about all rotational axes. Also, the weight of any device attached to the patient will be less than 10 lbs.

The CervPro device shall measure the angular position of the head across an ideal 80° and acceptable 60° RoM in either direction with error of less than 5%. The device will measure angular velocity of the head up to an ideal 60° per second and an acceptable 50° per second with an error of less than 5%. The position of any hardware of the device (if located on the patient’s head) will not shift more than 5° during 60° per second rotational speed. Any data collected will be saved to file while immediately displaying a therapist-defined output.

The CervPro device will not require Personal Protective Equipment (PPE) for operation.It will not emit sound louder than 60 dB, and any data transmission shall comply with relevant FCC and medical device regulations.

System Design

The CervPro device is a completely electronic device with no moving parts. The overall goal of the device is to measure patients’ head movements in every degree of freedom. The data capturing would be done by a single camera that records the patient performing the CPE test. The data is then sent to the microprocessor via USB cable to be analyzed. The microprocessor will run a program that uses facial recognition techniques to understand where the patients’ heads are in space and then will output movement information to the physical therapists. The device will be powered by plugging into a standard wall outlet.

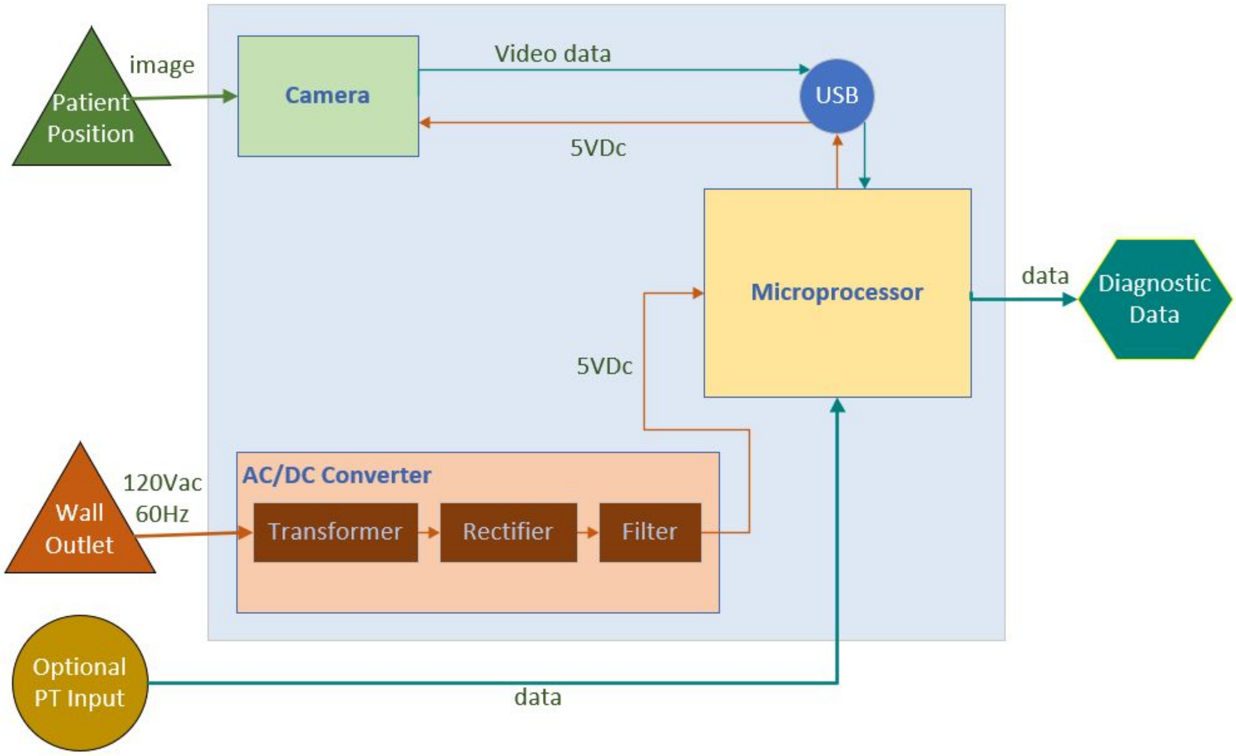

Figure 1. Functional Decomposition Diagram of the CervPro Device

Shown above is a functional decomposition diagram of the CervPro device. The overall system is fairly simple compared to some other senior design projects. There are 3 main subsystems in the device. Two of these subsystems require actual engineering. The camera subsystem has been purchased, not designed. However, the microprocessor and power system have been designed and will be fabricated next semester.

There will be 3 inputs that will be going into the device, the patients' head positions, power from the wall outlet the device will be plugged into, and some optional input by the physical therapist. This optional input hasn't been defined yet, but it will most likely be some sort of preference specification that the physical therapist will express to analyze the patients' head movements in a more specific way.

As shown below in figure 2, there are two human faces that the facial recognition program is finding. The program is tracing specific facial features with lime green lines to indicate recognition. This is an example of the program working on a single picture, but the program would be able to run this kind of analysis on video footage coming in at 30 frames per second. The program will then run some calculations based on the distances between certain pixels to find the closest approximation of where the person's head is in space numerically. These calculations will be based on the position of the patient's head at the beginning of their CPE test.

The power system in the CervPro device as mentioned before will draw power from a standard wall outlet. What's important to note conceptually about this diagram is that the power supply has three main components: a step down transformer, a rectifier, and a filter. The power supply will provide 5V of power to both the microprocessor and the camera.

Figure 2. Example of facial recognition program working on human faces

Detail Design

Controls Design

In order to analyze the motion of a patient's head, it was found that a video stream of 30 frames per second at 480p was the minimum quality needed for precise analysis. Microprocessor selection plays a very important role in the engineering of a product that can handle video analysis like this. The "Nvidia Jetson Nano" is the microprocessor that was selected.

Figure 3. Nvidia Jetson Nano - the microprocessor that was selected

This microprocessor was chosen because of the requirements needed to perform the operation fast enough in order to satisfy the technical specifications. From tests performed by another microprocessor, the Nvidia GeForce GTX 480, it was found that it was able to perform facial recognition at a speed of 30 fps at 480p. This was the predetermined “minimum” for sufficient quality of analysis. The camera that was selected records video at 60 fps, but the Nvidia Jetson Nano has twice the clock speed and data transfer rate of the Nvidia GeForce GTX 480. This should allow for operations at approximately 60 fps (700 MHz and 3.7 Gbps vs. 1.43 GHz and 25.6 Gbps).

The microchip microprocessors did not match the specs of the Nvidia GeForce GTX 480 and did not have a GPU, meaning that the performance of the algorithms would have been even slower. The Nvidia Jetson Nano was designed for use in computer vision applications and has been included in the design of many existing facial recognition projects. These facts all resulted in a sound decision to select the Nvidia Jetson Nano for the CervPro project.

Microprocessor Selection					
		ALTERNATIVES			
Decision Model		Nvidia Jetson		Microchip	
Criteria	Weight	Rating	Score	Rating	Score
OS	0.15	9	1.35	9	1.35
Speed	0.3	9	2.7	1	0.3
RAM	0.15	9	1.35	5	0.75
Storage	0.2	5	1	5	1
Interfaces	0.1	5	0.5	9	0.9
Power Draw	0.1	5	0.5	9	0.9
Total:	1	42	7.4	38	5.2

Figure 4. Decision matrix used for microprocessor selection

Figure 5. Comparison of Nvidia GeForce GTX 480 to other microprocessors

The OpenCV and Dlib libraries are being used for the analysis. These libraries are widely used and have been implemented in similar projects in the past. They are also widely accepted as having high accuracy. This is particularly important for the purpose of a medical diagnostic tool. Another advantage in going with libraries like these is that they include multiple different facial recognition algorithms. This would provide some design flexibility for the team in the scenario that a particular algorithm proves to be insufficient.

Existing tests on the different algorithms within these libraries exist that show the speed and accuracy approximations for the algorithms. The following chart is based on 10,000 tests per image on 10 images at 300x300 pixels. This is slightly smaller than the resolution that will be used in the analysis by the CervPro device. The algorithm that is currently being used is the MMOD algorithm with a GPU.

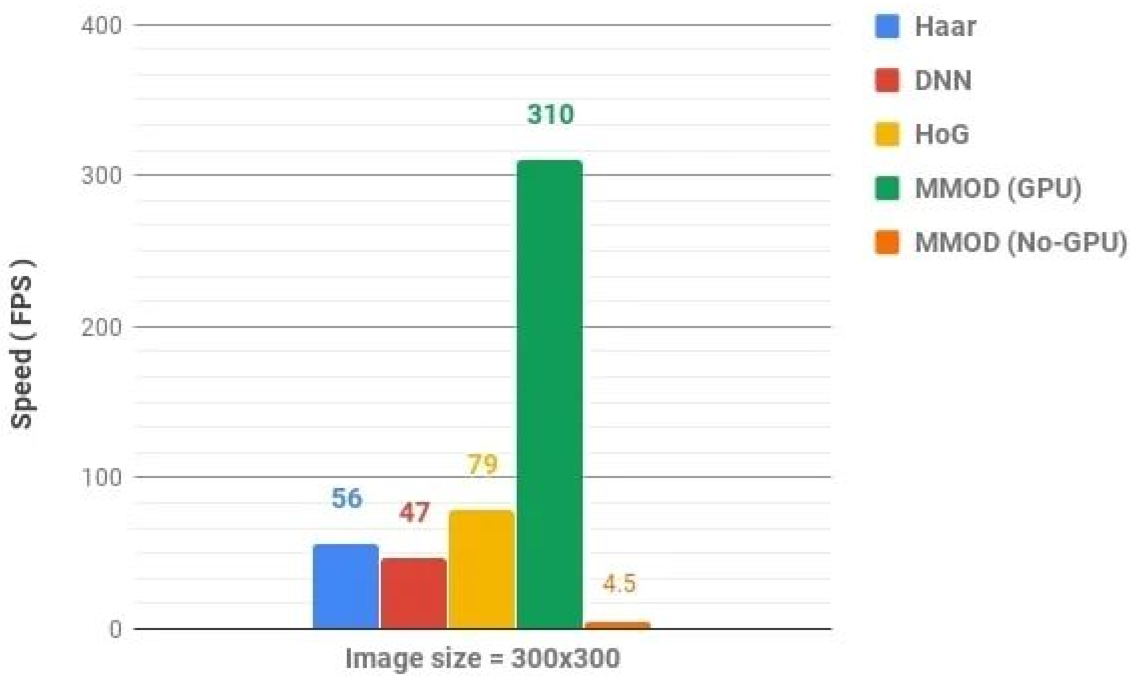

Figure 6. Comparison of different facial recognition algorithms within chosen libraries

A bluetooth microprocessor was also chosen because data needed to be transmitted to and from the main microprocessor and the user interface that the physical therapists will be interacting with. The exact specifications of the bluetooth microprocessor did not need to be incredibly specific. Because of this, the “BM71 Xplained Pro” bluetooth microprocessor was chosen. It was recommended by Microchip and will have quality support if there should be any problems developing with it. The main microprocessor will connect to the power system through a micro-USB cable. The power system will supply 10 W of power (5V 2A). The main microprocessor will be communicating with the camera through a standard USB cable, and it will communicate with the bluetooth microprocessor via standard USB cable.

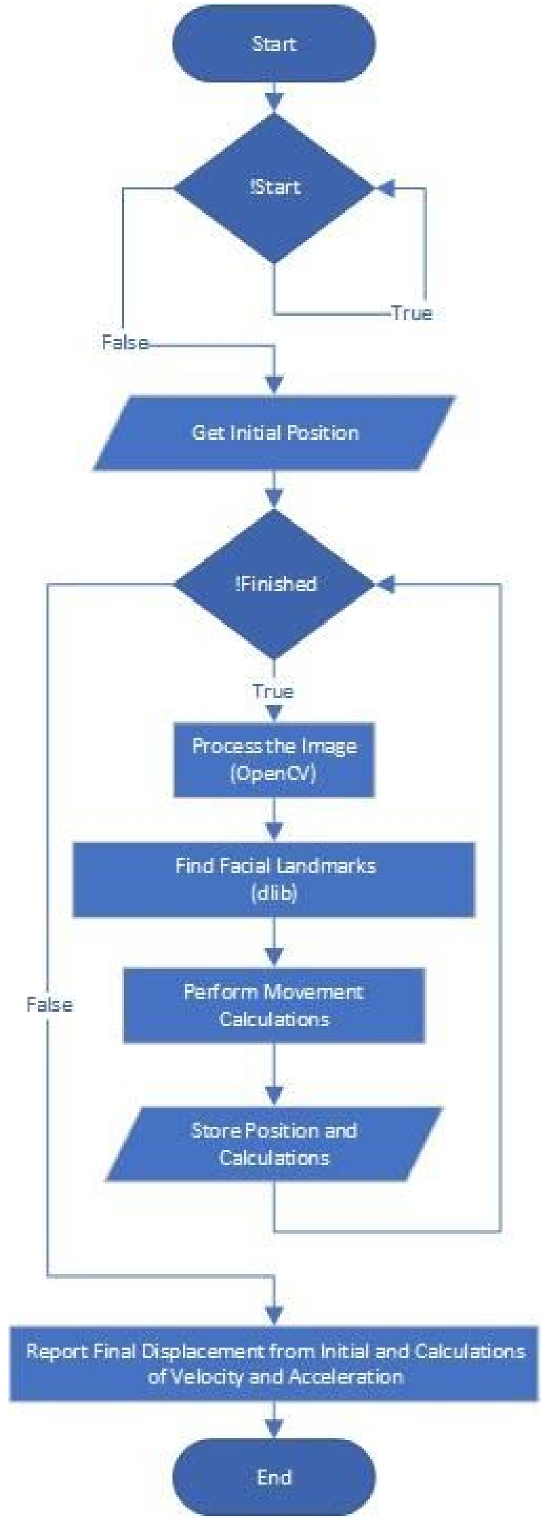

Figure 7. Flowchart showing overall structure of the facial recognition program

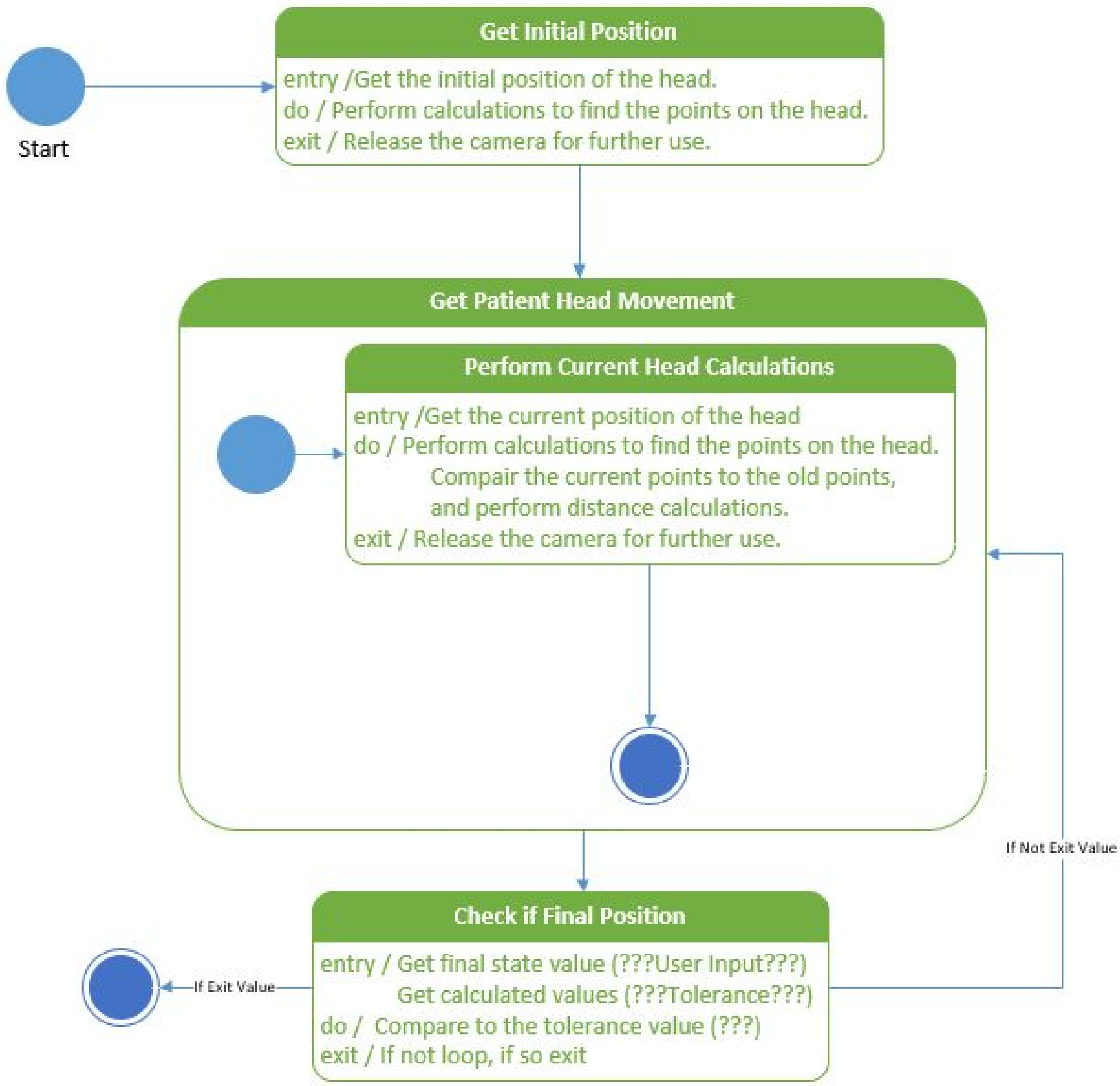

Figure 8. State chart showing different states and transition between them

Following this flowchart in figure 7 we will break down the program. The overall system is then divided into 3 different states, represented in the state chart in figure 8. The first state has the program waiting till the system is in use, in which case it takes the current position of the head and stores it. The second state then tracks the head as it progresses through the test, storing the position of the facial landmarks on each frame. This is done till the head reaches the end position. This end position will be found by either the physical therapist's input, or by the head staying in the same position, within a tolerance value, for a period of time (this will be decided by testing to see if a person can keep their head sufficiently still). When this is the case, the third state is entered. In this state, the final head position is stored and then compared to the initial head position, and the difference will be returned. In addition to that, any other calculated values, such as velocity and acceleration will be returned, as well.

This processing happens by having the image be converted, by OpenCV, into a state that can be used by dlib. dlib will then perform the facial feature finding and return the landmarks to the main program. These landmarks will then be stored, and the calculation of the instantaneous velocity and acceleration can be performed using this and the previous set of landmarks and the framerate of the camera, which will also be stored.

Camera Selection

As mentioned above, the minimum video quality needed for precise analysis was 30 frames per second at a resolution of 480p. The "Playstation Eye" is a commercially available last generation camera which can produce 480p uncompressed or JPEG compressed video at 60Hz with a 56° field of view. There were some specific needs that the camera needed to meet. The camera needed to be able to watch a human head of up to 17 cm in width rotate at angular velocities up to 60°/s. The camera will be roughly 1 meter away from the patient's head when recording. Given these specifics, several metrics for the camera were decided upon.

$$FOV\ minimum\ needed = arctan(1.5(0.17)) = 14.3^\circ$$

The field of view (FoV) must be able to see the entire face at the specified distance. The derived FoV was equal to the arctangent of 150% of 17cm divided by 1m, which is 14.3°. This is far narrower than the vast majority of commercially available cameras, however it does play a role in image quality. The image quality must sufficiently see a movement of 5% of 17cm (8.5mm) as one pixel minimum. The playstation eye running at 1m away from the face will have a pixel resolution cover 1m*tan(56°)/640pixels = 2.3mm. The camera must have a sufficiently fast enough frame rate to see one 5% movement at ideally 60°/s per frame, the nyquist frequency here works out to be

$$\left(\frac{2 * arctan(0.0085)}{60^\circ}\right)^{-1} = 61.6\ Hz$$

The playstation eye runs at 60Hz, which is slightly below the ideal value, but still acceptable. Finally, the camera must remain within budget and be solely run via USB-C connection with the microprocessor. The playstation eye narrowly won out against its direct competitor the Xbox kinect because of cost point, and it beat the more traditional logitech C922x for its comparable pixel resolution at range at a lower cost.

Figure 9. Image of Playstation Eye camera

Power Supply Design

The device for ease of use would be compatible with NEMA 5-XX outlets and would convert that 120±6Vac at 60Hz to necessary voltage for the device. The overall breakdown of a device for this would require 3 subsystems: a step down transformer, a rectifier, and a filter.

Initial designs were for 9V, an unknown current, and did not have a known signal to noise ratio. Once these values we-re adjusted to meet the microprocessor's needs viz 5±.01V (greater than 40dB reduction) and up to 4A (20W). Due to this higher than anticipated power rating, following best design practices a fuze was determined necessary. Besides adding the fuze and a final regulator IC, the original design was largely kept intact for its performance.

At this point, component selection required that all components were rated for the supplied voltages. This meant the transformer should be rated for at least 20 VA with a 10(+6/-3):1 turn ratio. After benchmarking the different possible transformers, it was discovered that doorbell circuits in homes often had 10 VA 1:8 transformers. Thus, an Edwards was chosen signalling 30 VA multi tapped 15:1, 15:2, and 4:1 (will not be used in the last configuration) transformer for a low price. Most other components were chosen for the design based on their availability in the engineering lab and conformance apropos voltage loads. The camera will be powered via a USB-C cable. The input to the power supply will be a NEMA 5-XX connector with 120VAC at 60 HZ, and the output from the power supply will be a 2.5mm male barrel connected with a 5VDC up to 4 A.

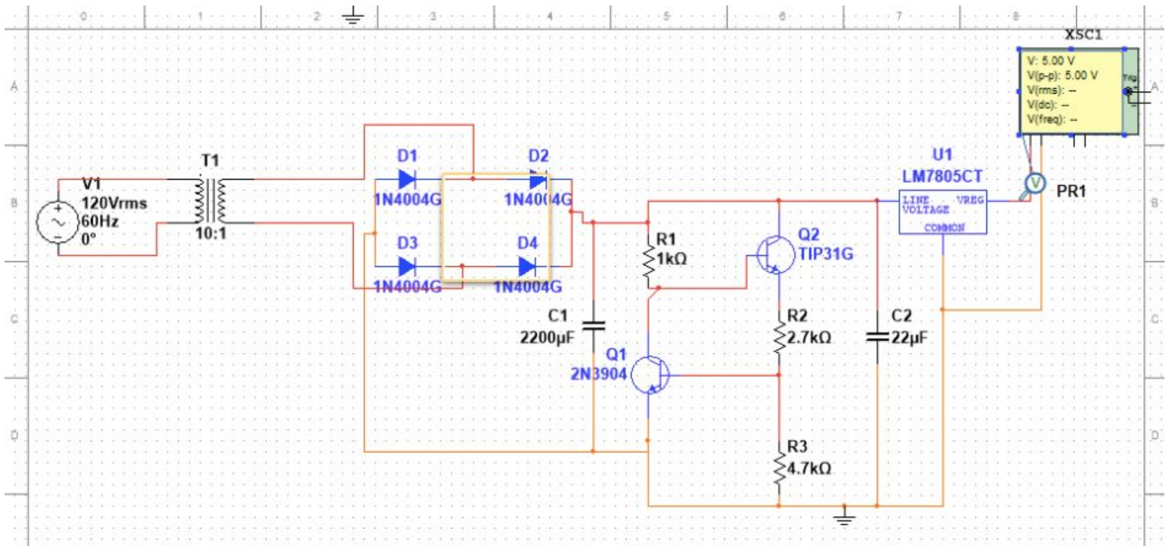

Figure 9. Schematic of power supply

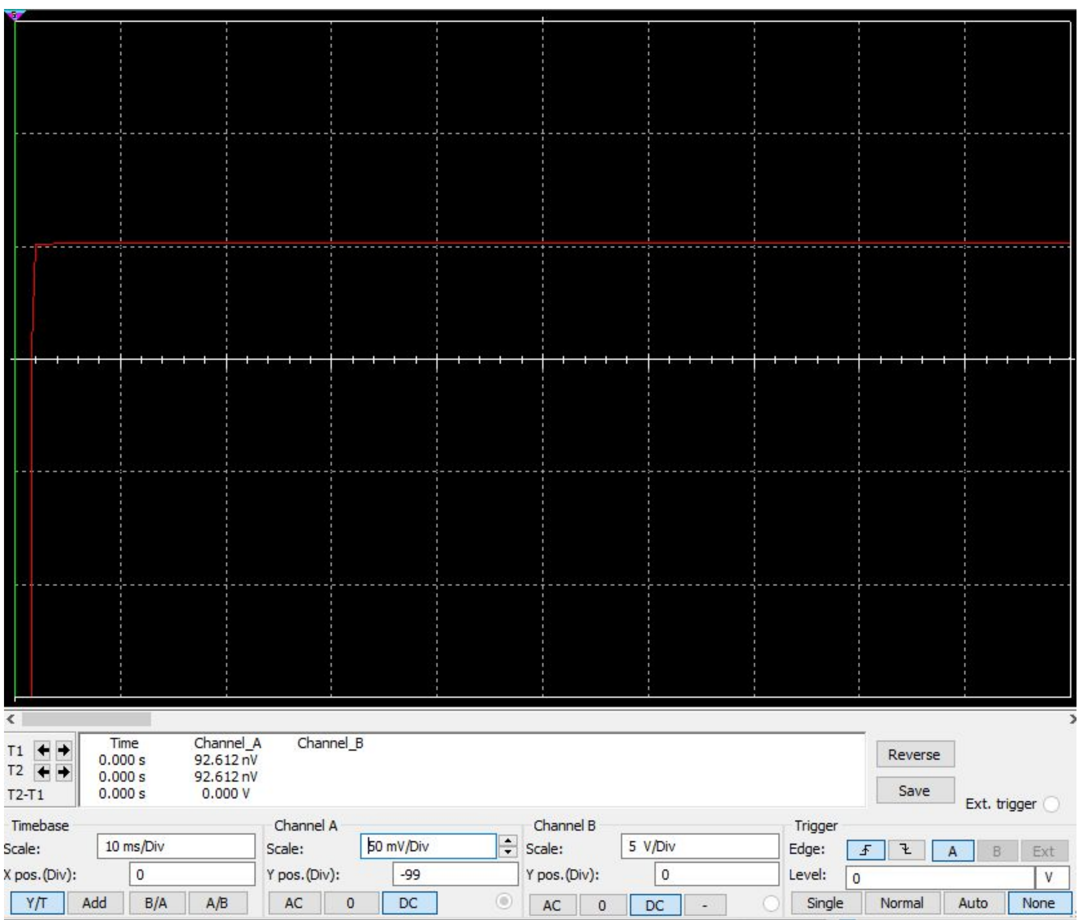

Figure 10. Output of power supply

Microprocessor Cooling Design

The operating temperature range of the Nvidia Jetson Nano microprocessor is -10°C to 50°C. In order to ensure the microprocessor wouldn't overheat during operation, some thermal analyses were conducted in solidworks.

The Nvidia Jetson Nano comes equipped with a heat sink in the form of fins. Natural convective air flow over these fin surfaces would certainly provide some cooling, but it was unsure if it would be sufficient to dissipate the heat generated by the microprocessor during long term use. In the SolidWorks study, boundary conditions were chosen to simulate the heat dissipation. In the study, an ambient temperature of 298 K was chosen, 30W of power was supplied by the microprocessor, the fins were discovered to be made of Aluminum 6063-O.

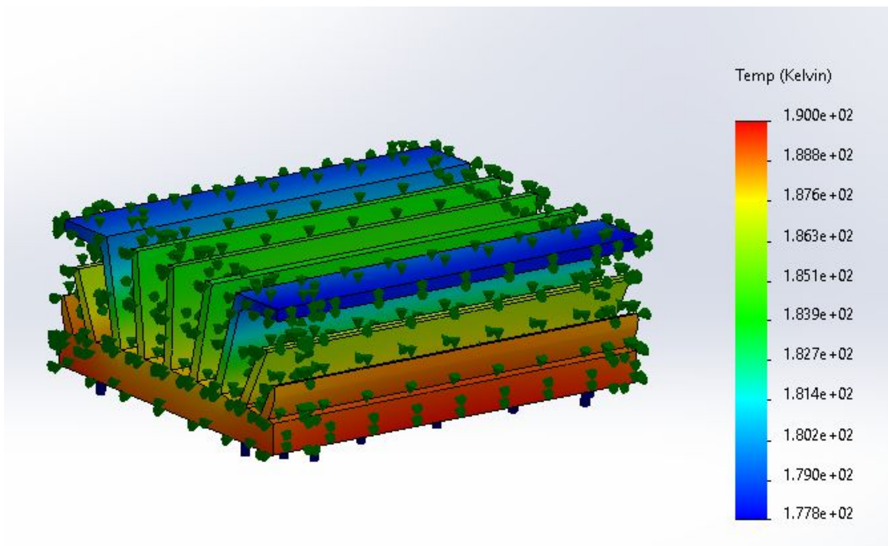

Figure 11. Heat sink under normal operating conditions with 2.5W/m^2.K convective coefficient simulating a natural convection. This is exaggerated for 300W/m^2 heat flux.

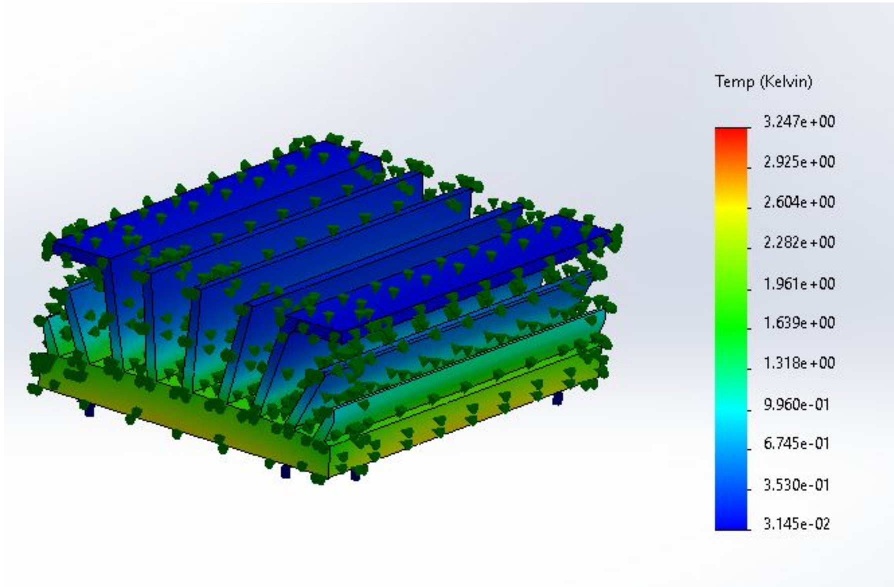

Figure 12. The fin temperatures when convective heat coefficient is 500W/m^2.K representing forced convection. Still exaggerated with high heat flux numbers.

The first solution was to purchase a ICE Cooling Tower which came with extra fins for more cooling surface area and a fan installed.The manufacturers had performed its effectiveness by running it on both normal heat sinks and ICE Cooling Tower. For the heat sinks, its operating temperature was 85 degrees celsius while with ICE Cooling tower, the temperature was reduced to 45-47 degrees celsius. The total cost is $24.90. The team decided to go with the ICE Cooling tower to ensure sufficient cooling for the microprocessor.

Figure 13. ICE Cooling tower mounted on the Jetson Nano Microprocessor

Project Management

Budget

	Qty	Price per each	Total Real Cost	Total Actual Cost
Power Subsystem				
Transformer	1	$24.97	$24.97	$24.97
1N4004	4	$0.00	$0.00	$0.12
2N3904	1	$0.50	$0.50	$0.50
TP31	1	$1.00	$1.00	$1.00
Resistor	3	$0.00	$0.00	$0.05
Capacitor	2	$0.00	$0.00	$0.05
LM7805	1	$0.00	$0.00	$0.75
PCB	1	$0.00	$0.00	$25.00
subtotal:			$26.47	$52.44
Camera Subsystem				
Camera	1	$37.29	$37.29	$37.29
subtotal:			$37.29	$37.29
Microprocessor Subsystem				
Microprocessor (main)	1	$100.00	$0.00	$100.00
Microprocessor (Bluetooth)	1	$60.00	$0.00	$60.00
ICE cooling tower	1	$24.90	$0.00	$24.90
64 GB microSD card	1	$15.00	$0.00	$15.00
subtotal:			$0.00	$199.90
Total				$289.63

Figure 14. Projected Budget for CervPro project

R.A.S.I.C.

		Core Team			
	Role\Person	Nathan	Ethan	George	Keneth
Mechanical	Cooling	I	C	I	R
	Device Housing	I	R	I	C
Computer	Microprocessor	C	I	R	I
	Programming	C	I	R	I
Electrical	Sensors	R	I	C	I
	Power	R	I	C	I
Reports	A3	A	R	S	S
	Proposal	A	R	S	S
Misc	Budget	R	C	I	I
Gov Cup	Prep	A	S		
Legal	IP	A	C		
	Compliance	A	C		

Figure 15. Responsibility Assignment Matrix for the CervPro project

Plan to Proceed

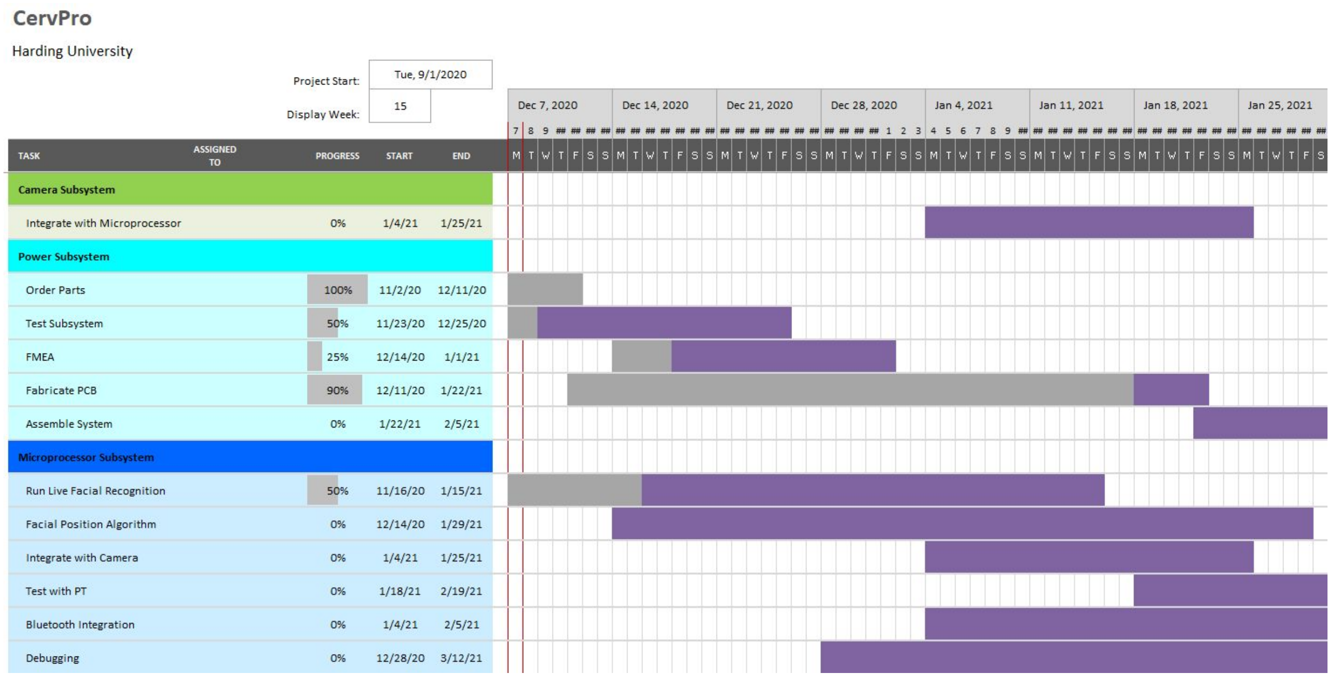

Figure 16. Gantt chart showing upcoming tasks and corresponding progress

Over the break, the team plans to test the power system and complete a PCB in order to eventually begin assembling the actual power system. There's still much to be done concerning the facial recognition algorithm and testing it. The team plans to begin testing immediately so that it can eventually be integrated with the bluetooth microprocessor and camera. By mid January, the team would like to begin testing the program with actual physical therapists.

Appendix

A.1 Prototype Demonstration Rubric

Technical Specification	Weight	100	80	60	30	0
Mean time for new therapists to run Cervical Position Error (CPE) test shall not exceed 10 minutes (double standard CPE time)	0.05					
Proportion of therapists able to make diagnosis exclusively using the device and within 40s of completing device cycle shall exceed 50%	0.05					

Hardware shall not significantly impede movements across an 80 degree Range of Motion (RoM) of the neck about all rotational axes.	0.05					
Weight of any device attached to the patient will be less than 10 lbs.	0.05					
Device shall measure angular head position across an ideal 80° and acceptable 60° RoM in either direction with error of less than 5%.	0.25					
Device shall measure angular velocity up to an ideal 60° per second and an acceptable 50° per second with an error of less than 5%.	0.25					
Hardware (if present) position shall shift less than 5° on the patient's head during 60° per second rotational speed.	0.05					
Data shall be saved to file while immediately displaying therapist-defined output	0.1					
Device shall not require Personal Protective Equipment (PPE) for operation	0.05					
Shall not emit sound louder than 60 dB	0.05					
Any data transmission shall comply with relevant FCC and medical device regulations	0.05					
Total	1.00					