California State University, Sacramento
Electrical Engineering and Computer Science Department

Senior Design II – Team CPM
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Mobile Knee Continuous Passive Motion
Final Documentation Report

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Executive Summary

This Senior Design, Team 7, project is to develop a functional and lightweight continuous passive motion (CPM) device. The purpose of this project is to offer patients undergoing post-surgery knee rehabilitation the ability to be less restrained while participating in rehabilitation sessions that aim to restore knee joint range of motion. In order to accomplish this task, Team 7 researched current specifications of standard CPM machines in order to create a foundation in which Team 7 would improve upon.

The CPM device in development, by Team 7, is a wearable that allows a patient to strap onto their leg in order to be used in a sitting position, but is not designed to be used while the patient is in motion. The CPM device will flex, and extend, the user's leg in order to provide range of motion therapy. Range of motion therapy is used to ensure that the patient's knee joint recovers to an optimum range of motion. The CPM device is designed to be lightweight, lighter than standard CPM machines on the market, which better allows for easy transportation and use. The CPM device is also designed to be user-friendly in the sense that it is: easy to attach, operate, detach, and store.

There are several integrated components used to complete the design of this CPM device: the frame of the brace (to hold the user's leg), the motor (to move the leg), the controller (to control movement of the motor), and power (needed to run the motor and controller). The brace used to hold the user's leg is designed to be scalable in order to fit onto a user's leg safely, in order to compensate for unique leg lengths and widths. The motor, used to move the patient's leg, has variable speed levels. Depending on the instructions of the prescriber; the motor will be extended and retracted within a safe and prescribed range. The motor of choice is capable enough to move an average person's leg mass with ease. The controller of the device was initially chosen to be physically wired that gives the user the ability to modify range of motion, speed, length of session, and start and stop switches. During the Spring 2017 semester, the controller is being recreated into an Android smartphone application that will allow the user to download onto their mobile device in order to control the CPM device. The power required for the CPM device is outside of the limits of battery operation so Team 7 has decided to use power from a wall socket in order to provide the necessary power needed by the CPM device and all of its components.

The CPM device is nearing completion as the proof of concept design is fully functional and the final refinements are currently being developed. After refining the CPM device, extensive testing on a subject will be performed to ensure full, and safe, functionality of the CPM device.

Mobile Knee Continuous Passive Motion Final Documentation Report

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***Abstract*—This reports details the work we have done over the last year in developing and building a Continuous Passive Motion device. Through the last two semesters we researched societal problems, market needs, and foreseeable risks. From this data we designed several solutions, choose the most suitable one, built and tested the chosen solution. Through various revisions we produced our desired deployable prototype.**

Keywords*—Continuous passive motion, work breakdown structure, risk assessment, deployable prototype total knee arthroplasty, linear motor, mobility, device, surgery, healing, range of motion therapy, testing.

I. Introduction

The purpose of a Mobile CPM device is to provide patients with a device that will help after knee surgery while being small. By making a Mobile CPM device, patients will not be confined to their bed as they recover and they could switch to a chair. Currently, CPM devices are large and unwieldy, see Figure 1 for example.

Figure 1: Typcial CPM Device Size [5]

The idea of a Mobile CPM device comes from an idea that the CPM device should be able to be used by a single person and not always need another to help them. A smaller and lightweight device helps more than just the patient as the device become more user friendly.

In this report, there will be an entire overview on Team CPM's design choices, funding, work breakdown structure, risk assessment, market forecasts, and various other things. From beginning to end, every decision that was made in the development of the Mobile CPM device will be explained.

Figure 2: Team Photograph

Elevator Pitch: *We are providing more mobility and freedom to those that need range of motion therapy.*

II. Societal Problem

Surgery after knee joint failure would typically lead to physical therapy and, possibly, the use of a CPM, Continuous Passive Motion, device. Total Knee Arthroplasty, TKA, is typically performed in the event of a knee joint failure. Knee joint failures usually happen due to osteoarthritis (OA), other inflammatory arhtritis', or recreation.

The purpose of TKA is to assist in pain relief and improve motor functions. In order for TKA to achieve its goals, damaged cartilage at interfacing surfaces of the femur, tibia and paella is removed. After the removal of damaged cartilage the damaged interfacing areas are resurfaced with artificial implants [2]. Once the surgery is complete, the patient may need physical therapy and CPM is an option that is capable of helping them.

In a comparative study of 50 consecutive patients; results yielded a significant decrease in the swelling about the knee [6]. However, there was no significant difference in the range of motion during an eight day postoperative focus. Increased costs incurred from the need for additional equipment and increase in staff time which made the device cost-ineffective and non-beneficial [6]. With the creation of a cheaper, alternative, device CPM is a viable option. According to Pope, a one year study in 1988 comprised of 53 patients, [3] shared a statistically significant increase in the range of flexion and total range of movement in the 0 to 70 CPM group compared to the no-CPM group. The results also indicated a significant increase in analgesic requirement and an increased mean blood drainage post-operatively in those who had 0 to 70 CPM treatment [3].

	Gender		Age in years	
Group	Male	Female	Mean	Range
No CPM	5 (*27.7*)*	13 (*72.2*)	69.6 (*64.4* to *74.98*)†	57 to 79
CPM 0 to 40	6 (*35.3*)	11 (*64.7*)	72.5 (*70.0* to *75.0*)	61 to 84
CPM 0 to 70	9 (*50.0*)	9 (*50.0*)	72.7 (*70.4* to *75.0*)	63 to 82

* percentage
† 95% confidence interval

Table I: Patients in three CPM treatment groups [3]

Early clinical research shows an important need for CPM devices and the benefits of physician assisted equipment. The existence of knee joint failure and the need for an easy implementable physical therapy solution is currently an ongoing issue.

Even with supportive studies, there are studies that contradict the benefits of a CPM. A recent 2016 study, regarding the effectiveness of CPM, on Range Of Motion (ROM) following TKA concluded that there are no clinical effects on postoperative recovery in respect to active knee flexion ROM and active knee extension ROM at different treatment times. Such studies may impact the implementation of these CPM devices, but having the option available is always a good thing. According to a 2008 Cochrane review, the short-term use of CPM leads to a greater short-term range of motion. Research has also shown that CPM should be implemented in the first rehabilitation phase after surgery. While there may be substantial debate about the duration of each session and the total period of CPM application, evidence suggests that the use of CPM devices whether used in conjunction with physical therapy are indeed beneficial to some patients and are very unique to their application. There are those who argue that the lack of evidence regarding the efficacy of these devices should prohibit continued use.

III. Design Idea

In order to solve the outlined societal problem, there will various parts that will need to be combined. The first to be addressed is the frame and structure of the CPM device. The frame of the CPM device will be created from an existing knee brace and then modified to fit the needs of a Mobile CPM device.

A mounting bracket will be created and attached to the frame, along the upper thigh portion of the frame, see Figure 3. This mounting bracket will be used to hold the linear motor and pulley system to the frame of the Mobile CPM device. The linear motor will be used in conjunction with a pulley and wire in order to extend, or retract, the CPM device.

Figure 3: Mounting Bracket

As the linear motor is powered, the motor will pull the wire and raise the patients leg, see Figure 8. The linear motor may also release the wire in order to lower the patients leg. As people are of differing sizes, there will be a need for a need to make the device adjustable in size. In order to create an adjustable Mobile CPM device a frame extensions will be created. The frame extensions will be used in order to adjust the size of the frame of the CPM device. The frame extensions will be modified by the physician during the initial fitting of the CPM device. The physician should ensure that the Mobile CPM device is fitted and safe for the patient.

Figure 4: Pulley system on mounting bracket

In order to keep the CPM device safe for patients, sensors will be installed along the brace to inform the CPM device that the user is wearing the device correctly. The simplest sensor will be a temperature sensor. The temperature sensor will be used to measure the patients leg temperature and compare that with the ambient air temperature. As the Mobile CPM device is meant to be used indoors, there is a general temperature that most rooms are placed at and human beings have an average temperature as well. When the leg temperature sensor is higher than the ambient air temperature sensor, the CPM device gets the okay to begin its routine. In order to use these sensors, there will be a need for a microcontroller.

A Parallax Propeller microcontroller will be the brains of the Mobile CPM device. The Propeller will read information from the sensors, temperature and the linear motor's potentiometer, and tell the motor driver to move the linear motor. The linear motors movement is capable of moving with the use of a simple motor driver. A simple mockup is found below in Figure 15 and Figure **??**.

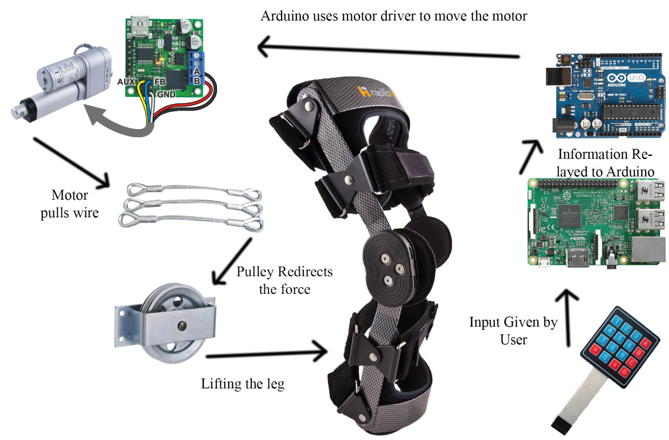

Figure 5: Device Operation

IV. Funding

The funding for the Mobile CPM device was completely provided by its group members. A portion of the parts needed for the project was already bought, due to earlier engineering classes requiring the hardware. The parts that needed to be bought were the linear motor, frame, and various smaller pieces. Tools that were necessary for the Mobile CPM project were already acquired as well. A breakdown in parts bought by various members of the group may be found below. A full cost breakdown of project components can be seen in Table II.

V. Project Milestones

The milestones of our project design life cycle are that of the start and completion of major components. These components are part of the three

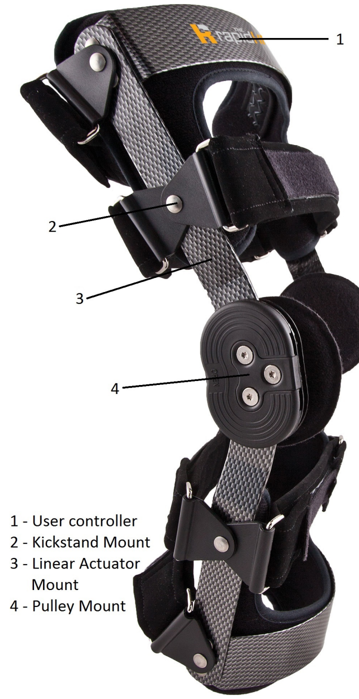

Figure 6: Design Idea Mock-Up [9]

Table II: Resources and Costs

		Quantity	Price	Min Price	Max Price
Hardware					
	18V Hammer Drill	1	$0.00	$50.00	$100.00
	18V Impact Drill	1	$0.00	$50.00	$100.00
	Parallax Propeller	1	$0.00	$10.00	$100.00
	Knee Brace/Harness	1-2			
	LCD Display	2-3	$0.00	$50.00	$100.00
	Linear Actuator	1-2	$130.00	$130.00	$260.00
	Miter Saw	1	$0.00	$100.00	$200.00
	Pulleys	1-4		$5.00	$10.00
	Remote Control/Buttons	1-5		$1.00	$10.00
	Temperature Sensors	1-2	$0.00	$1.00	$10.00
	Motor Driver	1-4		$5.00	$25.00
	Power supply	1		$5.00	$100.00
	High Tensile Wire	2			
	Velcro Strips	2	$5.94	$5.00	$10.00
	Velcro Straps	2	$11.92	$10.00	$15.00
	Nuts, Bolts, and Washers	25	$30.68	$25.00	$40.00
	Buck Converter	1	$6.55	$5.00	$10.00
	1/4 inch cable braid	1	$5.50	$5.00	$7.00
	1/2 inch cable braid	1	$10.99	$7.00	$12.00
	Power Jack Mount	5	$6.66	$5.00	$10.00
	Leg Brace	1	$49.00	$40.00	$160.00
	12V 5A AC Adaptor	2	$6.40	$5.00	$20.00
Software					
	SimpleIDE	1	$0.00	$0.00	$0.00
	IntelliJ JAVA IDE	1	$0.00	$0.00	$0.00
	Autodesk Inventor	1	$0.00	$0.00	$0.00
	Notepad++	1	$0.00	$0.00	$0.00
				Min Price	Max Price
Total cost				$514.00	$1,299.00

major features of our project, either being involved with the smart phone application, the frame, or the electronic components box (ECB).

A. Design Idea Finalization

At this point, our initial laboratory prototype design was agreed upon in the group and submitted for acceptance by the professors. We listed out our features we wished to implement, who would implement what component, what resources were needed for each component, and the cost associated with each. This design is for our first semester lab prototype.

B. Assembled Linear Motion

This part of our project milestone is completing the linear motion into the use of our project. We used a linear actuator and attached it to the frame of our device to pull a wire linearly, but translate linear movement to angular motion for the knee joint.

C. Assembled Hardware Controller

In the first semester, this controller was completely built using an LCD screen, mechanical key switches, a 3D printed body, and Ethernet cable attachment to the frame of the device. This allowed the user to manipulate variables involving range of motion, speed, timing, and start and stop functionality.

D. Integrated Potentiometer

Up to this point, our actuator was not accurate in its movement as we have just been testing for proper extension and flexion range. At this point, we implemented code to read data from the potentiometer, giving us accurate movement and location data at all times.

E. Integrated Power Regulation

For the first semester of the project, the power system was driven by battery for the linear actuator and usb cable for the control system. We initially planned to run the whole system off of a 12V 5A

AC adaptor from the wall. After some testing and discussions with Professor Matthews, it was decided that the linear actuator could be dangerous to the control system if ran on the same power system because of feedback from the stall current generated when the linear actuator starts and changes directions. Our options were to design a feedback filter guard, or separate the power systems. We decided to separate the power systems because it was the safest and most reliable method to prevent damaging the control system.

F. Completed Lab Prototype

After completing the hardware controller, actuator movement and location, power regulation, and frame attachments, we combined all individual components to assemble our laboratory prototype to serve as a proof of concept for the final presentation.

G. Frame Redesign

Second semester, we had much to iterate on to bring our project to completion. The first aspect of which is the frame redesign. Our lab prototype was a hacked together mess with hand-bent steel for our mounting bracket. This semester, we made sure to submit our bracket design early to avoid any mishaps with the Mechanical Engineering Fabrication Lab. In addition to the fabricated mounting bracket, we also included a scalability factor to our design. This addition was also started at the same time as the mounting bracket design

H. Electronic Components Box

In the first semester, our electronic components were exposed to the user. Since we are making a wearable device, we do not want our users to be in danger of exposed wiring. To remedy this, we house all of our electronic components in a compact box similar to a laptop power supply. This design takes in power from the wall socket and sends signal from the housed microcontroller to the frame.

I. Controller Application

Instead of staying with the physical wired controller of the first semester, we instead decided to harness the widespread use of smartphone devices. Due to time constraints and cost, we started and completed development only for Android OS devices. This application consists of the same functionality as the hardware controller, except through Bluetooth instead of Ethernet connection.

J. Deployable Prototype

Our completed deployable prototype was completed on April 23, 2017 that fulfills all feature set items detailed in our design idea contract. The device performs all functions listed as well as supports specified weight, range of motion, and lengths of individual legs while maintaining lightweight and simple design.

VI. Work Breakdown Structure

A. Jonathan Huggins

Jonathan will be in charge of research, design, and construction of the Mobile CPM device. Jonathan will work in tandem with Deryk in order to modify the frame. The research Jonathan does will help determine which pieces will need to be modified and how in order to accomplish the goal.

B. Deryk Su

Deryk will be in charge of safety and construction of the Mobile CPM device. The safety of the device will be a mechanical stop that is built into the frame of the device as well as sensors. There will also be a temperature sensor that needs to be programmed into the microcontroller. As well as safety, Deryk will also be doing the construction and modifications of the Mobile CPM device.

C. Matthew Boyle

Matthew Boyle has experience with 3d modeling in AutoCAD and Inventor which will allow him to model and design the parts necessary for building the Mobile CPM device. Matthew also has experience assembling and testing electronic equipment needed to operate the Mobile CPM device and build the ECB.

D. Elias Carrasco

Elias's role is to tackle the programming of the microcontroller and Bluetooth application. In addition to writing the software, Elias will perform quality assurance on the code, testing for unknown behavior, and preventing harmful bugs. Elias will work with Matthew in order for the hardware and software to work together seamlessly.

VII. Risk Assessment

There are various risks associated with creating a Mobile CPM device. The risky parts are the frame, motor driver, linear motor, remote, and safety of the device. In order to have a successful device, there will be a need to mitigate the risks associated with each part of the CPM device. See Table III to determine the amount of risk for each part of the CPM device.

In order to mitigate risks with the frame of the device, testing will be done in order to determine if the weight of the leg, linear motor, and modifications are too much. Testing for an extended period of time will give the necessary information to determine if the device is capable. The frame size is another risk, but that will be determined when adding the components together. Measuring and allocating the appropriate distances for the motors and modifications will take care of the frame size risk. Modifying the frame itself is a risk as well and there will be tests that insure that the frame stays intact while modifying and adding on parts.

The linear actuator will have a motor driver to power it. The motor driver needs to be rated up to above the proper amperage, which in this case 10 amps. By using a 10 amp motor driver, in the event of feedback from the motor driver the motor driver will be able to handle it. As for the risk associated with the linear motor itself, there are very few risks. The motor driver was purchased and already pretested to be proven and reliable.

With the controller, the biggest risks are that of the application not working, or Bluetooth not working. The controller is the patients own personal smartphone. If the patient does not have a capable smartphone, then they will be unlikely to control the system. The Bluetooth application is coded for modern smartphones so a majority of them should work fine. Bluetooth is also a standard protocal these days, and that means the connection should be simple and clean.

Safety of the device is taken care of with the frame itself, as it has its own locks on the range of motion. Temperature sensors can easily be added and removed as necessary, so risk of the sensor breaking is minimal. Every piece of the CPM device is securely attached, so there will be no need to worry about parts falling off and injuring the patient.

VIII. Design Overview

The Mobile CPM device is created using an everyday knee brace, linear motor, unistrut, a pulley, wire, nuts, and bolts. In order, the process of creating the Mobile CPM device required the modification of the knee brace. The two metal bars, that make up the structure of the knee brace needed to be removed from the fabric. Once removed from the fabric, the metal bars will need to be prepped for parts to be attached. The metal bars will have holes drilled and then tapped. By tapping the holes, screws will be able to be used in order to combine the parts.

The metal bars are to be moved to the outside of the fabric; held in place with Velcro. On top of the right metal bar, a mounting bracket is placed.

Impact					
		Low	Medium	High	Very High
Likelihood	Very High	Microcontroller	Sensors	Communication with Actuators	Insufficient space on Frame
	High	Polling Rate	Range of Motion Measurements	Linear Actuator Accuracy	Driver Calibration
	Medium	LCD and Button Integration	Kill Switch Failure	Insufficient Power to Actuators	Weak Safety Integration
	Low	Button Ghosting	Linear Actuator Failure	Driver Failure	Knee Frame Fracture

Table III: Risk Assessment Table [8]

This custom piece of metal will be mounted with multiple nuts and bolts, firmly securing the frame to mounting bracket. Once the mounting bracket is attached to the frame, the linear motor is mounted to the bracket. Mounting the linear motor requires the use of two pipe clamps. These clamps are tightened securely enough so that the linear motor does not move when the CPM device is in action.

The linear motor is attached to a wire that runs over a pulley, and down to the bottom of the frame. At the bottom of the frame there is a screw and nut that will secure the end of the wire. By doing attaching the end of the wire to the bottom of the frame, as the linear motor retracts, the bottom part of the frame will ride upwards. See Figure 7 for an image of the linear motor and 8 for the pulley system.

In order to power the linear motor a Electronic Control Box, ECB, was created. This ECB contains the microcontroller, motor driver, and Bluetooth module. The ECB controls the power that is delivered to the linear motor as well as the signals sent and received. The best part of the ECB is that it is independent of the CPM device, as it is only connected by wire and not actually a part of the frame itself. See Figure 9.

The last piece of the CPM device is the controller. The controller for the CPM device may be any Bluetooth enabled Android smartphohe. The smartphone will need a custom code to run the application at first, then connect to the CPM device by Bluetooth. After connecting, the patient may control the CPM device as they wish, or to stop it as well.

Figure 7: 4 Inch Linear Actuator with Potentiometer

Figure 8: Pulley system on mounting bracket

IX. Deployable Prototype Status

The status of our prototype is in good shape. The Mobile CPM device is built, sturdy, and works. The CPM device was tested for its scalability and structural integrity. THe CPM device was also tested in the event that the ECB is dropped and the

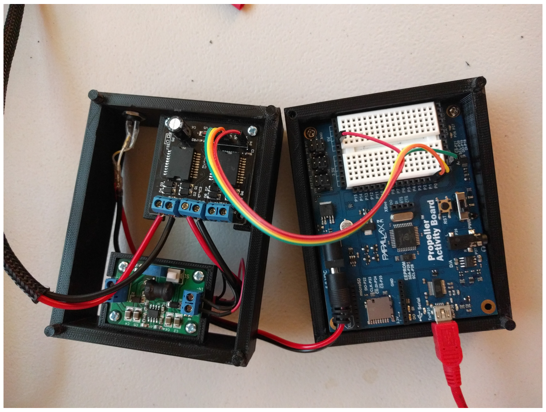

Figure 9: ECB PLA Case and Components

Bluetooth controller was also tested.

The CPM prototype was tested with the new frame extensions and it was found to have around an extra ten inches when fully extended. Each of the four frame extensions were moved around and tested to make sure they could reach intended points and hold that position.

While frame extensions are good for scalability, see Figure 22, there is also the weight component when they are added to the frame of the device. The CPM device had to be tested with the new weight of the frame extensions attached. As each extension weighed two pounds, the test included: the frame, frame extensions, and a leg. As the device was being used, the CPM device and its frame did not seem to have difficulty performing the necessary functions. The CPM device was tested to hold around 30 pounds for 30 minutes and therefore passed.

Figure 10: Frame Slider extension

The ECB was tested by dropping the device from heights of one to six feet while loaded with five pounds of weight. The ECB did not break during these tests and passed. There was also temperature regulation tested on the ECB. Allowing the CPM device to run for several hours, the internal ECB temperature was measured to max out at around 40 degrees Celsius while the material used to make the ECB melts at 200 degrees Celsius, with deformation beginnning at 150 degrees Celsius. Temperature testing of the ECB passed as well.

Testing the Bluetooth application was the final piece as there was a need for this to be reliable. The CPM device is fully controlled by the Android smartphone it is connected too. The first test was a distance test, how far one could move away from the CPM device and still control it. Moving away from the CPM device, about twenty five feet with clear line of sight, the connection was still good and passed the tests. In order to ensure that data is not leaked when running, the Bluetooth connection uses Secure Simple Pairing, SSP [4]. This test comprised of trying to connect to the Bluetooth module while another connection was already established. The test resulted in only one connection being allowed at a time, meaning it passed the test.

Overall, the prototype is finished and can be seen in Figure 11. There are few changes that could be done to make the device more aesthetically pleasing. There may be other ways in which weight could be lowered as well, but as it is a rapid prototype the device is fully functional in its current state.

X. Market Forecast

While this deployable prototype is nearly complete, there are several items that need refining before such a device can be sent for manufacturing. For instance, the fabric that is attached to the frame is not long enough for larger patients. To remedy this, we could use a stretchable, yet durable, fabric that allows a better fit for a wider range of people. Also, the device is not quite flexible enough to be

Figure 11: Deployable Prototype

used by those with abnormal leg shapes such as those with bow legs or knock knees. Because of this, the device will not fully operate in its full range of motion due to the spacing left between the user's leg and the frame of the device. This also warps the steel, and moves the pulley system to an unsafe location in which the wire begins to grate against it.

Due to the wide range of patient leg sizes and shapes, our device would need to be able to form its shape around the user's leg, no matter what shape or size. For our project, we were not able to remedy this issue, but it would need to be solved somehow before this prototype is sent to manufacturing.

Before the software segment can be released further testing would have to be done, and adjustments would have to be made. First we placed the motor at fixed points and calculated the angles from linear motion based on those fixed points, but as the motor can be moved around more than just the few points we picked to calculate the motion at there is a strong need to add either an analog solution to estimate where the motor has been placed, or to lock it down to only allow fixed point placement and resolve the issue.

Another software issue that needs to be addressed is streamlining the Bluetooth connection process. As it stands right now the connection needs to be established by the user, and it would be a nice feature to have it automatically connect to the Bluetooth module in the ECB to save time, and to reduce clutter on the application interface. The last issue that would need to be addressed is the time synchronization. If the user starts and stops the device multiple times, the time remaining will not match up exactly correct. This is due to the fact that when the phone application stops it saves the millisecond it was on, and the phone application pauses at the nearest second.

XI. Conclusion

Working on the CPM device throughout senior design taught us a lot about working in a team, on a project, and also about ourselves. While working on the societal problems and brainstorming for solutions we had many grand ideas. It wasn't until we actually working on the project that we understood the scope of the work, money, and time needed to implement those ideas. Teamwork is crucial for the success of a project, particularly communication. Several times in the course of our project we ran into issues that could have been solved with proper communication. While each person worked on their own individual part there were few problems, when we combined our parts together there was usually an interfacing issue that came up. Through the semesters, we found that properly documenting our work allowed our teammates to more efficiently integrate our parts into theirs.

Limitations in the project came up as the project progressed. Several parts broke in the development of the CPM device and we were forced to make the decision between time, money, and work. This applied not only to broken parts but to the development of improvements made to the device in the second semester. A shortage of time required us to work harder or smarter as the project required, such as using a dual power system over designing a new feedback filter circuit for the ECB. Other times money would supplement work, such as buying a linear actuator with a build in potentiometer rather than having to design an angular measurement system ourselves. Sometimes spending extra time was inevitable, in most cases this came from the code as debugging always took more time than anticipated.

Despite running into many obstacles throughout this past year, our final project is one that we are proud of. While our CPM device is not exactly what we had first planned it is fully functional and does what we set out to do by providing more mobility and freedom to those that need range of motion therapy.

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Appendix A
User Manual

Package contents:
1 x Leg Brace Frame
1 x Electronics Controls Box
2 x AC to DC Power Bricks

Setting up the leg brace:

Figure 12: Leg Base Framework

1. First get into a comfortable position in a chair if possible, and then open up the Velcro straps throughout the device.
2. Next, position your leg in the device such that the two side metal supports are parallel, or close to parallel.
3. Then begin tying down the Velcro straps preferably from the top.
4. Make adjustments as needed to keep the metal supports close to parallel as possible
5. Once all the straps are tied down grab a pillow and place it under your leg, and get ready to set up the other components.

Setting up the Electronics Control Box:
1. Place the box close enough to a wall outlet such that the cable length isn't strained.
2. Next, plug in the two AC to DC power bricks to supply power to the whole device.

3. Then plug the ends of the power bricks into the control box.

Figure 13: Power Plug Connector

4. Now that the whole device is powered on another component can now be setup
5. A debug port is available if major issues arise, and values can gathered from the serial COMM port. It will show the time, angle, speed, current position as well as the goal position. In order to use this feature both of the power supplies should be unplugged to avoid any hazards, if a live test is needed then the power input closet to the edge of the box will power on the motor.

Setting up the phone application:
1. First obtain the android phone software from your physician.
2. To install in developer options turn on installations from third parties, as this will allow you to install the software as it isn't available on an app-store.
3. Open up the application package with ending .apk and the phone will prompt the user if they wish to install the software. Say yes.
4. Open up the app on the phone, and the controls will be on the interface. Speed controls how fast the motor operates as a percentage of its max speed. Angle will tell it how far to bend at the knee. This is shown in Figure 14 below. Last is time this is time remaining in seconds. This is set up by the clock application on the device which is different for every phone model.
5. Once the interface has been made familiar, and all other parts have been set up. Input a time, and press start to begin operation.
6. The red stop button will stop the device by fully extending the motor, and then holding there. This will allow you to comfortably get out of the device.

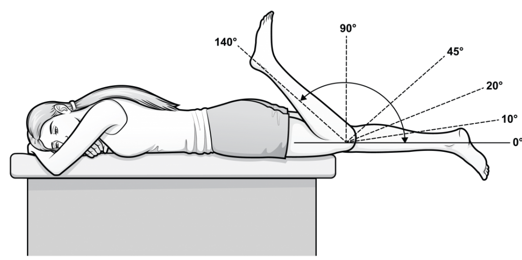

Figure 14: Healthy knee range of motion [1]

Appendix B
Hardware

A. Device Components

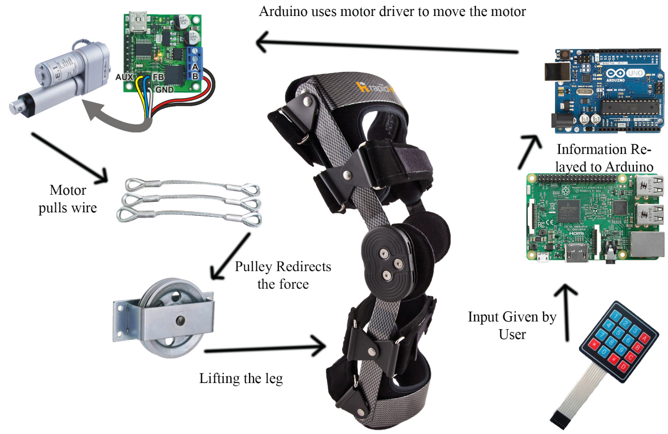

Figure 15: Device Operation

Figure 15 displays the entirety of the project in terms of its combined component levels.

B. Test Plan and Test Results

Test	Tester Name(s)	Start Date	Finish Date
Linear Motion	Jon	2/6/17	2/13/17
Pulley System	Jon & Deryk	2/6/17	2/20/17
Frame Integrity	Jon & Deryk	2/13/17	2/27/17
Frame Scalability	Jon & Deryk	2/13/17	2/27/17
Wireless Connection	Elias	2/13/17	3/10/17
Data Protection	Elias, Jon, & Deryk	2/13/17	3/10/17
App Functionality	Elias, Jon, & Deryk	2/13/17	3/10/17
ECB Connection	Matt	2/13/17	2/20/17
AC Outlet Connection	Matt	2/13/17	2/27/17
AC/DC Conversion	Matt	2/13/17	3/10/17
Motor Driver Temp	Matt	2/6/17	2/27/17
Box Fidelity	Jon, Matt, Deryk, & Elias	2/13/17	2/27/17
Cable Strength	Jon, Matt, Deryk, & Elias	2/13/17	2/20/17

Table IV: Device Test Plan Timeline [7]

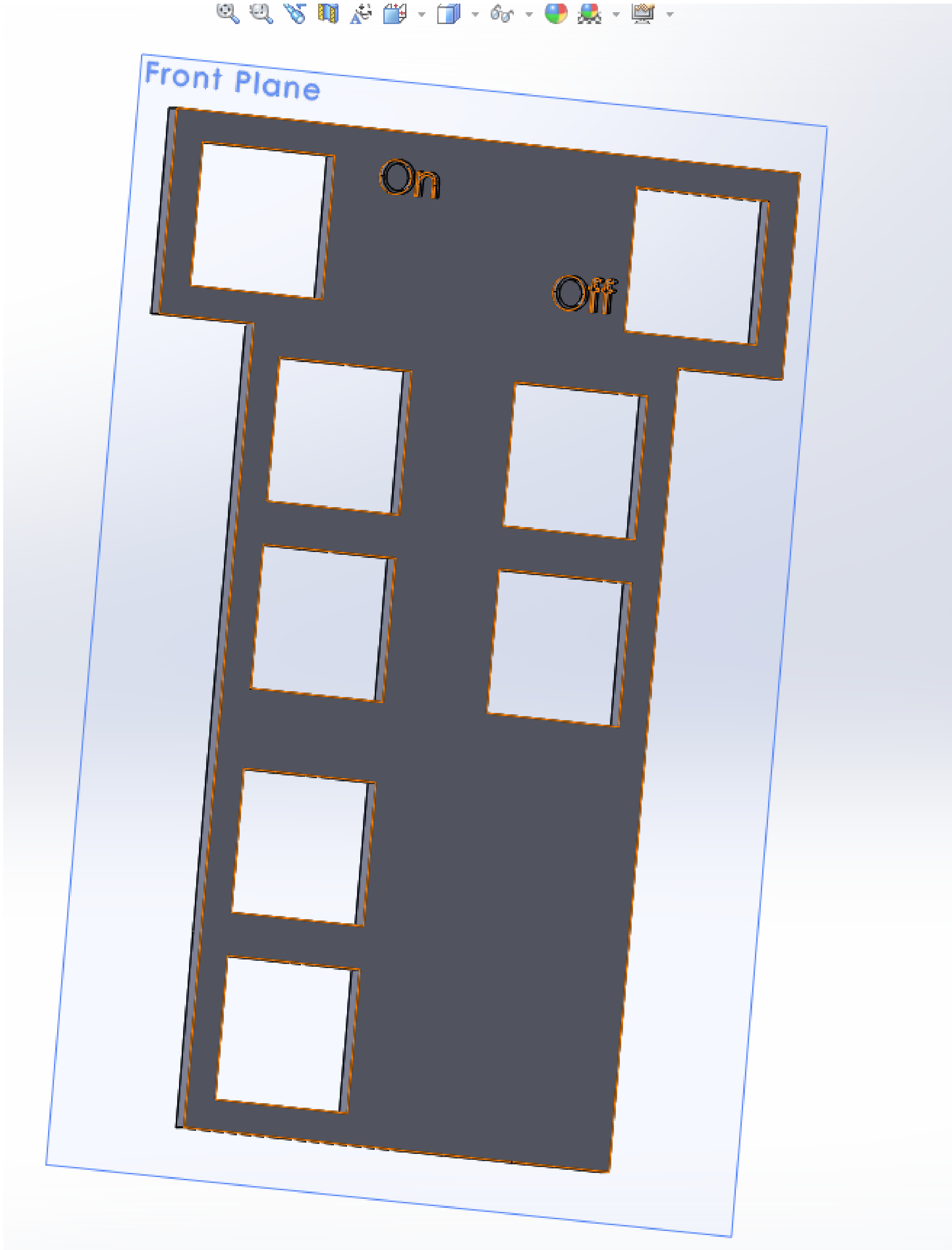

Figure 16: First Semester Controller Body Design Version 2

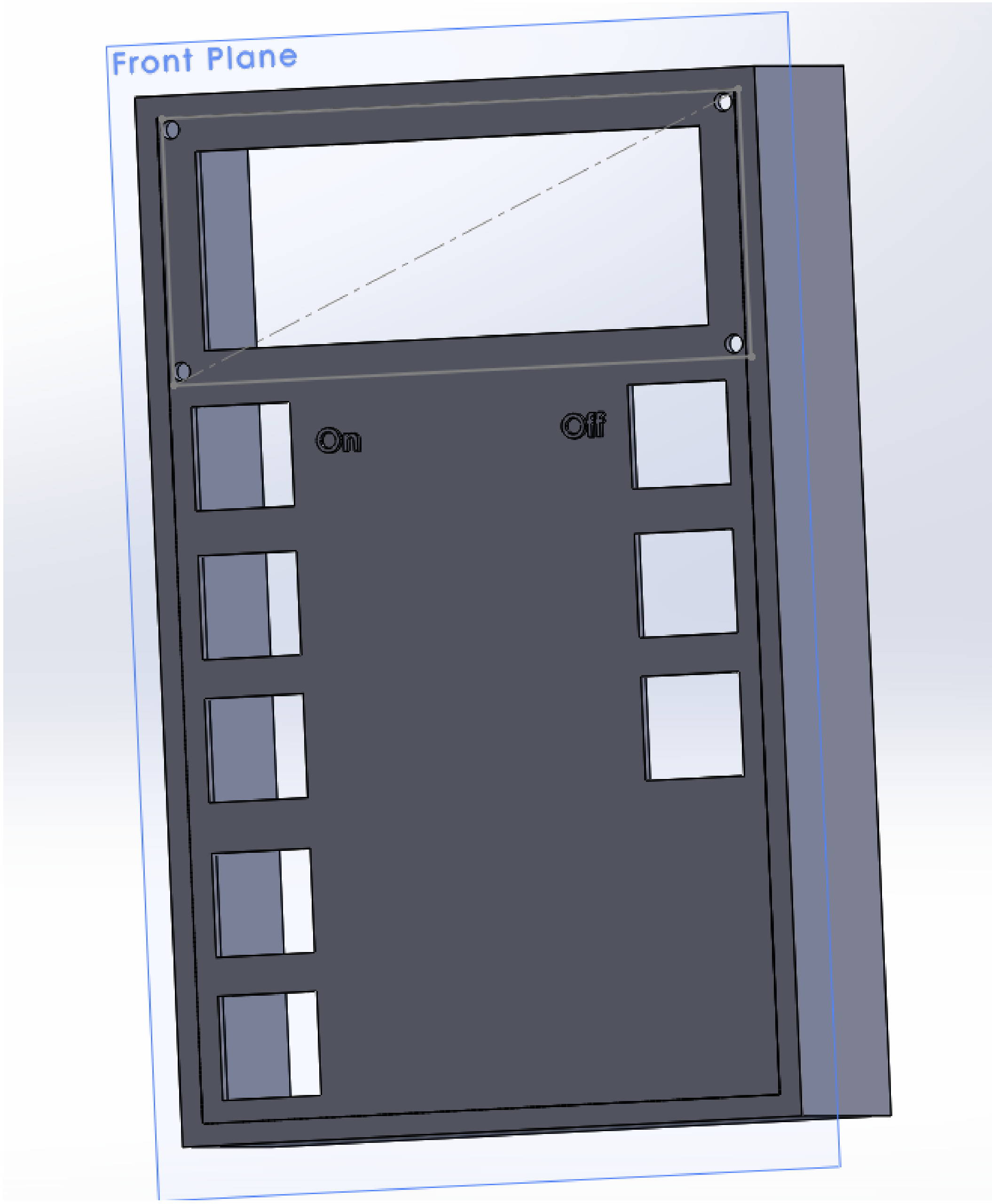

Figure 17: First Semester Controller Body Design Version 3

Section	subsections	Unit of Measurement	Functionality	Resources/Tools	Test Plan
Frame	Linear Motion	inches	linear motion to angular	ruler	Test the extension and retraction of the linear actuator to determine if device can operate between 0 and 90 degrees.
	Pulley System	pounds	transform linear to angular	protractor	Test weight limits of pulley system to ensure lasting use of the device while supporting leg weight on the joint. Also testingtransformation of linear movement to angular to ensure full range of motion movement.
	Frame Integrity		holding leg weight (40 lbs)	group member's leg	Test frame strength after screw holes drilled into existing frame. Measure distances between screw holes (~1 inch). Test if frame can support group member's leg weight.
	Frame Scalability	inches	extend brace size 6-10 in.	ruler / group member's leg	Test slider extension and retraction. Measure distances using ruler to receive exact values. Test location of linear actuator to ensure sliders do not interfere with positioning. Test slider extension and frame strength using group member's leg weight.
Android Application	Wireless Connectivity	feet		measuring tape and phone	First connect the phone and the CPM device. Then place the bluetooth module 10 feet away from the phone. Afterwards we will turn on several wireless devices to simulate the expected environment. Last we will check to make sure the device and phone are still communicating using a test program.
	Data Protection	bytes	data encryption	bluetooth module, and 2 phones	Pair the phone and the CPM device with SSP. Then open the same application on another device, and check to see if the CPM device changes its values from external sources.
	Compatibility		works on many devices	multiple smartphones	Pair a phone with the CPM. Then remove the first phone and pair it with a different device. Repeat the previous two steps until we have no more different phones.
	Functionality		replaces remote	smartphone	Test how the app and CPM will behave when unexpected, or erratic user input is inserted.
Electronics Components Box	ECB connection		Connect controller to motor	cat5 cable	commands will be inputted through the system to ensure that that cables are properly connected, the wires will be bent and pulled to ensure the cables stay in place.
	AC outlet connection	Amps	connect ecb to power outlet	three pronged power cable	AC adapter will be tested to ensure the proper voltage and amperage is outputed and is useable by the ECB
	AC/DC conversion	Amps	convert AC to DC	AC to DC converter	AC adapter will be tested to ensure the proper voltage and amperage is outputed in DC at 12V 2A
	Temperature Regulation	farenheit	prevent overheating of components	fan/ventilation	Box will be designed with vetilation. Temerature sensors will be placed in the box with components running to measure peak values, if measured values are too high then a fan will be installed and it will be retested
	Box Fidelity	pounds/farenheit	box capable of withstanding heat and drops	3d printer	The box will be printed to absorb impact and with proper ventilation. It will need to be printed out of ABS or a more heat resistant plastic. We will fill the box with weights and drop it with increasing heights and load. For heat testing we will test it with a range of temperatures to at varying distances from the plastic.
	Cable Tensile Strength	pounds	allows pulley system to work	braided cable	Cables will be run over with rolling chairs and twisted and bent till they break. We will measure the number of times bent to break or damage the wires, then try again with cable braiding cover.

Table V: Device Test Plan Table [7]

	Timeline		
Test	Tester Name(s)	Start Date	Finish Date
Linear Motion	Jon	2/6/17	2/13/17
Pulley System	Jon & Deryk	2/6/17	3/10/17
Frame Integrity	Jon & Deryk	2/13/17	2/27/17
Frame Scalability	Jon & Deryk	2/13/17	3/10/17
Wireless Connection	Elias	2/13/17	3/10/17
Data Protection	Elias, Jon, & Deryk	2/13/17	3/10/17
App Functionality	Elias, Jon, & Deryk	2/13/17	3/10/17
ECB Connection	Matt	2/13/17	2/20/17
AC Outlet Connection	Matt	2/13/17	2/27/17
AC/DC Conversion	Matt	2/13/17	3/10/17
Motor Driver Temp	Matt	2/6/17	2/27/17
Box Fidelity	Jon, Matt, Deryk, & Elias	2/13/17	2/27/17
Cable Strength	Jon, Matt, Deryk, & Elias	2/13/17	2/20/17

Table VI: Revised Device Test Plan Timeline [7]

Testing Items

Section	Subsections	Unit of Measurement	Functionality	Resources/Tools	Test Plan	Results
Frame	Linear Motion	inches	linear motion to angular	ruler	Test the extension and retraction of the linear actuator to determine if device can operate between 0 and 90 degrees.	Successful, leg can be extended to straight while sitting (0 degrees) and relaxed to the ground (90 degrees)
	Pulley System	pounds	transform linear to angular	protractor	Test weight limits of pulley system to ensure lasting use of the device while supporting leg weight on the joint. Also testing transformation of linear movement to angular to ensure full range of motion movement but attaching weight to wire and moving weight vertically by moving wire horizontally.	Successful, pulley system is able to support 35 lbs moving vertically with horizontal wire pulling
	Frame Integrity	pounds	holding leg weight (40 lbs)	group member's leg	Test frame strength after screw holes drilled into existing frame. Measure distances between screw holes (~1 inch). Test if frame can support group member's leg weight first with no modifications, then with only sliders attached, and finally with mounting bracket and actuator attached	Successful, frame is able to support weight of leg plus additional slider weight for a total of 29.5 lbs
	Frame Scalability	inches	extend brace size 6-10 in.	ruler / group member's leg	Test slider extension and retraction. Measure distances using ruler to receive exact values. Test location of linear actuator to ensure sliders do not interfere with positioning. Test slider extension and frame strength using group member's leg weight.	Successful, 6 inch slider extensions are able to extend 5 inches to add a total of 10 total inches to frame length
Android Application	Wireless Connectivity	feet		measuring tape and phone	First connect the phone and the CPM device. Then place the bluetooth module 10 feet away from the phone. Afterwards we will turn on several wireless devices to simulate the expected environment. Last we will check to make sure the device and phone are still communicating using a test program.	Successful, 10 feet was achievable even with a variety of obstructions placed in the path of the device.
	Data Protection	bytes	data encryption	bluetooth module, and 2 phones	Pair the phone and the CPM device with SSP. Then open the same application on another device, and check to see if the CPM device changes its values from external sources.	Success, with two phones having the app open only the device that was currently paired could send or recieve data.
	Compatibility		works on many devices	multiple smartphones	Pair a phone with the CPM. Then remove the first phone and pair it with a different device. Repeat the previous two steps until we have no more different phones.	Works on Samsung S7, has not been tested on other types of devices.
	Functionality		replaces remote	smartphone	Test how the app and CPM will behave when unexpected, or erratic user input is inserted.	Successful, even if the user tries to change many inputs simultaneously only one can change at a time, as it is blocking all other inputs (adroid side)
Electronics Components Box	ECB connection		Connect controller to motor	cat5 cable	Commands will be inputted through the system to ensure that that cables are properly connected, the wires will be bent and pulled to ensure the cables stay in place.	Cables are safely mounted to components and sucessfully transmit data
	AC outlet connection	Amps	connect ecb to power outlet	three pronged power cable	AC adapter will be tested to ensure the proper voltage and amperage is outputed and is useable by the ECB	AC adaptor sucessfully outputs 12v at 6A consistently
	AC/DC conversion	Amps	convert AC to DC	AC to DC converter	AC adapter will be tested to ensure the proper voltage and amperage is outputed in DC at 12V 6A	AC adaptor sucessfully outputs 12v at 6A consistently
	Temperature Regulation	farenheit	prevent overheating of components	fan/ventilation	Box will be designed with vetilation. Temerature sensors will be placed in the box with components running to measure peak values, if measured values are too high then a fan will be installed and it will be retested	Tempature within ECB was not measured to exceed 40C after 4 hours of testing with current ventilation. No fan will be needed.
	Box Fidelity	pounds/farenheit	box capable of withstanding heat and drops	3d printer	The box will be printed to absorb impact and with proper ventilation. It will need to be printed out of ABS or a more heat resistant plastic. We will fill the box with weights and drop it with increasing heights and load. For heat testing we will test it with a range of temperatures to at varying distances from the plastic.	Box will melt and warp after being exposed to 150C for more than 10 seconds, operational temperature of the propeller activity board and other components is 70C so components will shut off before box will deform. ECB was filled with 5lbs and dropped from 6 feet without any damage to it, actual weight of components will be under 5lbs and it is not anticipated to be above 6 feet
	Cable Strength	pounds	Protects wires between ECB and Frame	braided cable	Cables will be run over with rolling chairs and twisted and bent till they break. We will measure the number of times bent to break or damage the wires, then try again with cable braiding cover.	Cables broke after 73 ninety degree bends, running over them with 200lbs in roller chair did not sucessfully break them after 20 attempts with shielded cabling. Broke without shielded cabling after 12 attempts
	DC Voltage Stepper	Volts	Lowers main Voltage to ranges Propeller can use	Multimeter	Voltage stepper will be calibrated and tested to output between 9 to 6 volts	Voltage Stepper was calibated to output 8.07 Volts consistently

Table VII: Device Test Plan with Results Table [7]

APPENDIX C
SOFTWARE

First we have a Parallax Propeller microcontroller, which is controlling all the logic of our design. The features that the propeller has that are utilized are parallelism, high precision timing, and rapid prototyping.

The software parallelism is broken down into a handful of pieces. At the very top is the master thread, or hypervisor which allocates resources to the threads, or cogs below it. This structure is shown in Figure 18, after the master has started, it gives resources to both the PWM which is run separately from the rest, and the Bluetooth. The Bluetooth thread contains the parameters for the instructions, and when the correct instruction is received will initiate the motor.

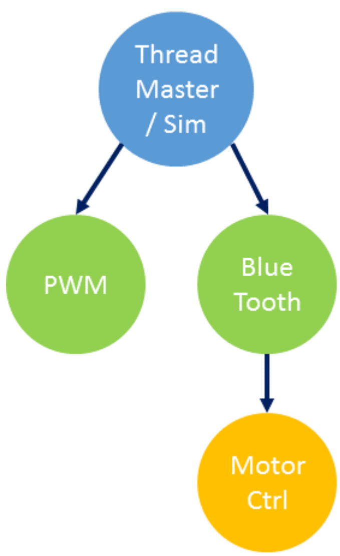

Figure 18: Software Multithreading

The instruction set is shown in VIII, and the layout for the instructions is shown in 18. The instructions are sent into the propeller in one byte chunks. The first is used to determine if there is input from the phone app as well as the most significant bits of the data if applicable, and the second would contain the data being passed in. At this stage in the design the instructions were picked to provide the data that we needed, as well as to allow for expansion in the future as people may request new features, and leaving room for expandability allows for easy growth.

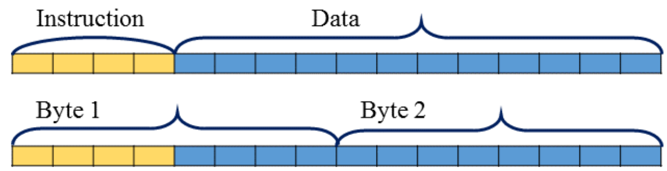

Figure 19: Instruction Layout

One additional feature that needs to be explained is the reasoning for breaking the data into both bytes. The reason for this was to address run time on the device. Since the phone application doesn't have a seconds input and only goes down to minutes, then we have to send the data in as minutes. Additionally, the longest interval the interface can input is 24hours. Taking 24 hours and multiplying by 60 minutes we get the largest possible value of 1440 which can't fit in an 8 bit value (8 bit values max out at 255), but comfortably fits in 12 bits.

The last discussion item from Table VIII is the final instruction with hex value of 0xF, and the reason this is unusable is because the Bluetooth module will output a -1 when the Bluetooth's buffer is empty and not stop the whole process, and -1 in binary is represented by all bits set to 1, so instruction 0xf may cause conflicts if used and the data segment also happens to have all bits set to 1. To avoid that situation altogether, this instruction is unusable. Any instruction not explicitly stated is up for future developers to make adjustments to.

To test this software package on the microcontroller without having to plug in the linear actuator a temporary simulation provided stimulus to the design under test (DUT) which was the Bluetooth thread. The reason for testing this module was

0x0	reserved
0x1	send angle
0x2	send speed
0x3	send time
0x4	reserved
0x5	reserved
0x6	reserved
0x7	shutdown system
0x8	
0x9	
0xa	initialize system
0xb	
0xc	
0xd	
0xf	unusable

Table VIII: Instruction Set Architecture

because it spawned all the other threads other than the pwm which is simply awaiting for input from the motor thread. The goal then was to see how it would react to inputs from the Bluetooth, and it would make adjustments to the motor values to simulate changes in the potentiometer in the actuator. By simulating the motor we could guarantee that the entire software solution was working as intended.

One part left out was the phone application. The reason it wasn't tested with as much vigor was due mostly to the fact that the microcontroller handled the Bluetooth communication, and the phone simply sends data. Therefore the only testing that was done was for functionality, and ensuring that the values matched on both ends after sending data.

APPENDIX D
MECHANICAL

Frame Integrity Tests			
Phase	**Device Weight (lbs)**	**Holding Weight (lbs)**	**Duration (minutes)**
No modifications	3 lbs	25 lbs (leg only)	30 minutes
Sliders attached	12 lbs (previous weight + 4 sliders @ 2.25 lbs each)	29.5 lbs (leg and 2 bottom sliders)	30 minutes
Sliders and Actuator attached	16 lbs (previous weight + actuator @ 2.9 lbs + mounting bracket @ 1lb	29.5 lbs (leg and 2 bottom sliders)	30 minutes

Table IX: Device Tests for Frame Integrity

Figure 20: Brace with attachment holes drilled and threaded

Figure 21: Machined steel mounting bracket for pulley system. The mounting bracket design was developed with the requirement of supporting 35 pounds of weight.

Figure 22: Frame Slider extension

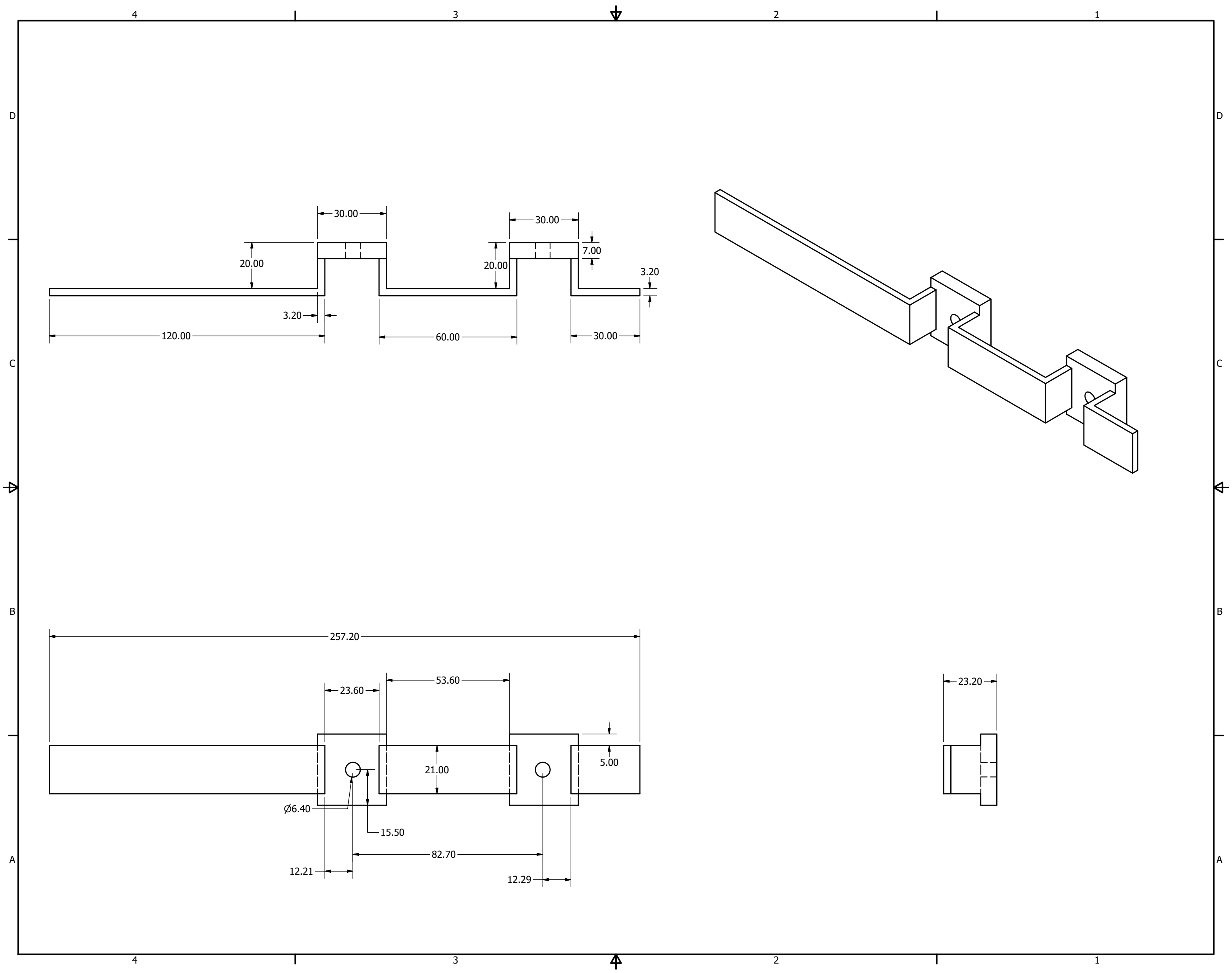

Figure 24: Bracket Design from Sketches in Figure 23 made in AutoCAD Inventor

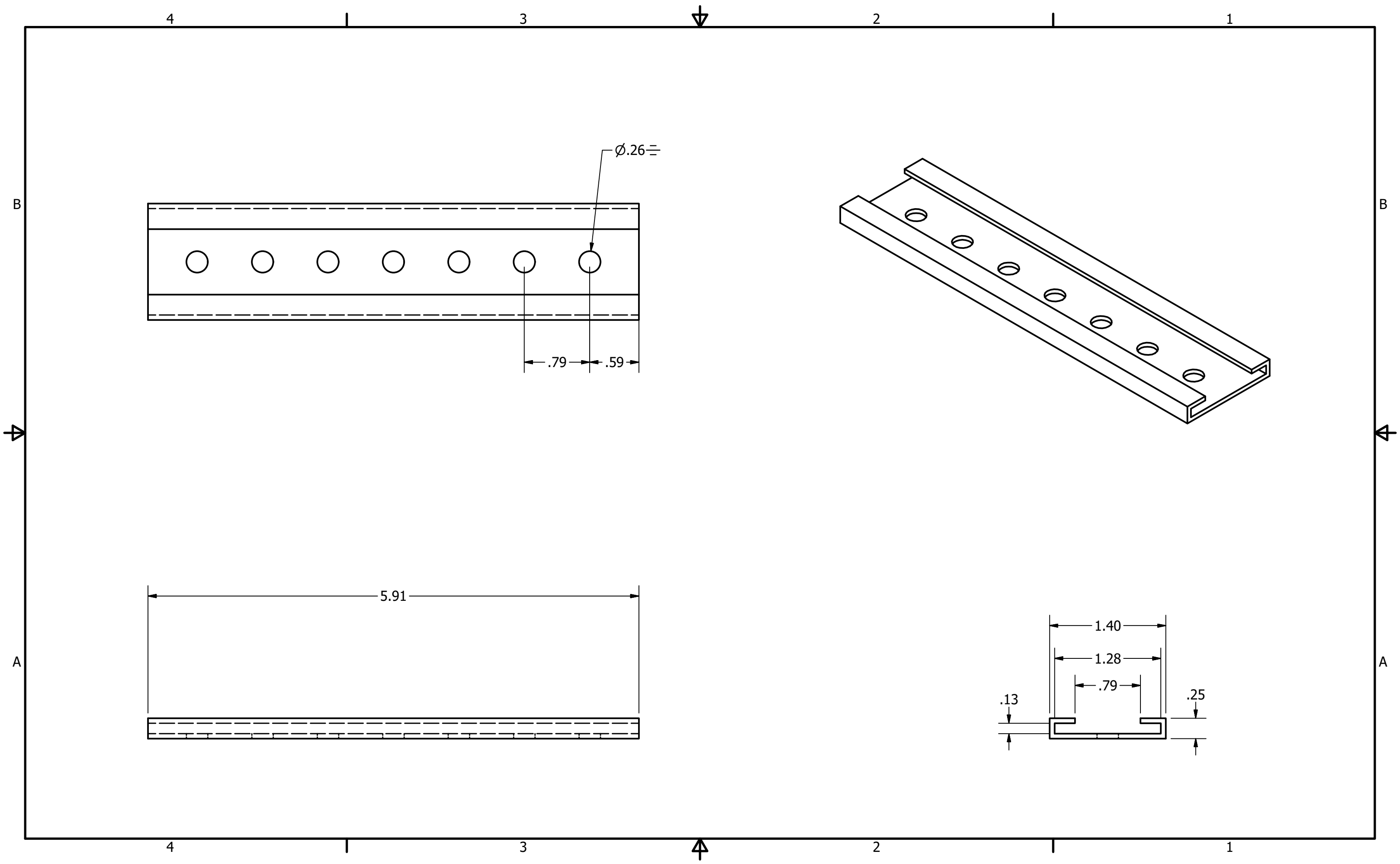

Figure 25: Extension Design in AutoCAD Inventor

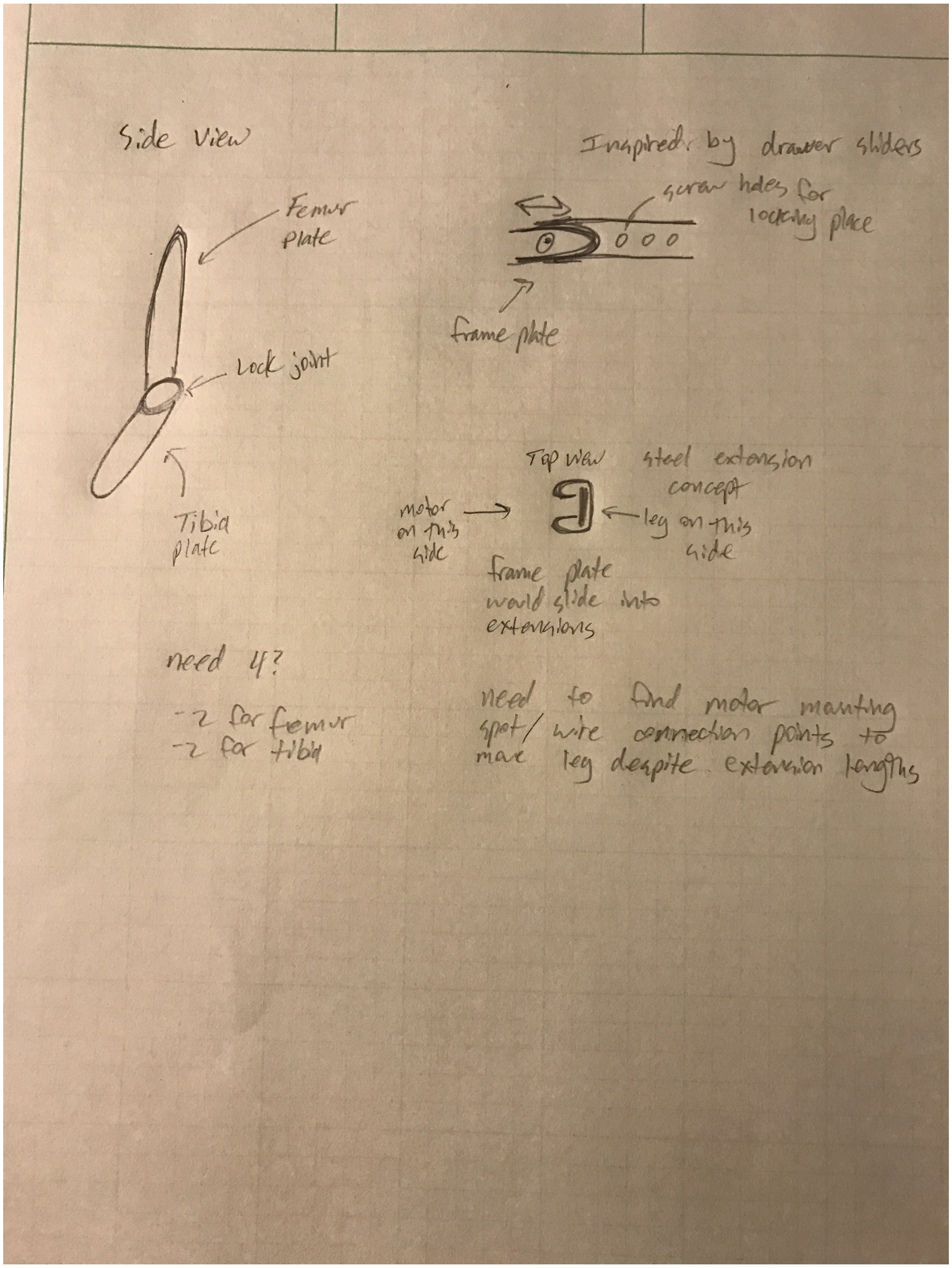

Figure 23: Frame Extension Concept Sketches

Appendix E
Vendor Contacts

A. Off Campus Vendors

- Amazon
- Fry's Electronics
- Home Depot
- Lowes
- Polulu

APPENDIX F
GROUP MEMBER RESUMES

Jonathan Huggins

Education

In progress: BS, Computer Engineering, CSU Sacramento, 3.6

***Related Coursework**:*

Computer Hardware Design	Advanced Computer Organization	Advanced Logic Design
Electronics I	Signals & Systems	Computer Interfacing
CMOS & VLSI	Probability & Random Signals	Operating System Pragmatics
Intro to System Programming in Unix	Data Structures & Algorithm Analysis	Robotics
Computer Networks and Internets*	Senior Design II*	

**in progress as of Spring 2017*

Knowledge & Skills

Computer Languages: C/C++ • Java • X86 Assembly • Python • Verilog (HDL)

Operating Systems: Linux • UNIX • Windows • OS X

Software Applications: Quartus • Xilinx ISE • VIM • PSpice • Multisim • MS Visual Studio • MS Office Suite

Design Tools: Synopsys VCS • Oscilloscope • Function Generator

Projects

RISC Pipeline Data path

As part of a two-person team implemented a five stage, sixteen-bit instruction, MIPS pipeline data path using the Synopsis VCS tool to calculate basic integer arithmetic, register forwarding, hazard detection, and branching. The data path decodes the type of hexadecimal instruction and executes for that particular instruction type. Outputs are visible using waveforms.

Mobile Continuous Passive Motion Machine

As part of a four-person team implemented a lightweight, attachable, small-footprint continuous passive motion device to assist patients with post-operation knee joint range of motion therapy. The device slowly flexes and extends a patient's leg with control from an Android smartphone application via Bluetooth to a microcontroller and uses power from an AC wall outlet.

Work Experience

MATH TUTOR | KUMON MATH & READING | 09/12 – 07/15

Assist student learning in the areas of Calculus and Algebra

Activities & Accomplishments

- Member, Tau Beta Pi
- Dean's Honor List

Deryk Su

Education

California State University Sacramento, Sacramento, CA, Computer Engineering – 3.3 GPA

- Dean's Honor List
- Association for Computing Machinery, Member, 2015
- Tau Beta Pi, Member, 2015

Experience

CalSTRS – Student Assistant – Client Technology Services (CTS), West Sacramento, CA

November 2016 – Current

- Provide deskside support to CalSTRS customers with hardware, software, network and application related problems, or questions
- Operate and provides support to CalSTRS audio/visual equipment
- Image desktops and laptops with Windows, configure CalSTRS workstations and install user required software
- Inventory audit, deploy workstations, schedule and relocate CalSTRS customers and erasure of CalSTRS equipment
- Processed tickets with responsibility for timely documentation, escalation, resolution and closure
- Assist team members in relocations, troubleshooting, and daily tasks, as needed

CalSTRS – Student Assistant – IT Service Desk, West Sacramento, CA

April 2015 – November 2016

- Assisted CalSTRS customers with hardware, software, network and application related problems, or questions
- Processed daily system and network access requests following ITIL methodology
- Performed laptop maintenance, inventory audit, processes daily workflows and follow up on existing tickets
- Worked on projects as needed, examples include: organizing system documentation in the Service Desk Wiki and perform CA Unicenter profile clean up

Intel Ultimate Engineering Experience, Sacramento, CA

Summer 2012

- Participated in a six-week hands-on training program, with a diverse team, in order to learn the process engineers use to: identify, troubleshoot, and solve complex real world issues
- Built a remote-control drone that would connect to a PC via Wi-Fi, documenting problems along the way
- Engineered a solution for shoes while traveling, to prevent deformation in baggage

Projects

Mobile Continuous Passive Motion (CPM) Machine

- As a four-person team, implemented an attachable, lightweight and small CPM machine to assist post-operation patients with range of motion therapy.
- Process included research and extensive documentation as well as the modifications to existing equipment
- Engineered a solution that flexes a patient's leg, with control from a Bluetooth Android application

Knowledge and Skills

- Computer languages: X86 Assembly, C/C++, Verilog, and VHDL
- Knowledgeable in: Active Directory, System Center Configuration Manager, TeamViewer, Windows Remote Desktop Connection, VOIP Telephones, Symantec End-Point Protection, Multisim, PSpice, Quartus, Xilinx ISE, Adobe and MS Office
- Chinese (Cantonese) and Spanish
- Assemble, debug, and maintain high end workstations

Matthew Boyle

LinkedIn: www.linkedin.com/in/matthewcreswellboyle
Ironferret2313@gmail.com

Education:

California State University, Sacramento: *2015 – May 2017*
In Progress: BS, Electrical Engineering: GPA 3.338

Santa Rosa Junior College: *2008 – 2015*
Associates of Science in Natural Sciences
Associates of Science in Mathematics
Associates of Science in Physics
Associates of Science in Engineering

North Bay Christian Academy: *2004 – 2008*
High School Diploma

Skills:

MultiSim, P-SPICE, ADS, MS Office, Photoshop, Autodesk Inventor
Soldering, circuit design, power management, 3D printing, milling
Windows, Linux, C/C++, Assembly Language, Javascript

Relevant Classes:

Feedback Systems
Electronics I and II
Intro to Microprocessors
Intro to Logic Design
Signals and Systems
Probability & Random Signals
Robotics
Control Systems

Projects:

Micro-mouse Maze Solving Robot
Quadcopter
Mobile Continuous Passive Motion Device
Self-Assembled 3D printer
Functioning 3D Printed Iron-Man Boot
Robotic Navigational Unit

Experience:

Costco, Costco Associate: *June 2012 – June 2015*

- Cashier Work
- Warehouse Stocking
- Inventory Management
- Seafood, Meat, and Deli Work

Sears, Sales Associate: *November 2010 – March 2012*

- Customer interaction, Cashier and money handling skills Computer and research skills

Target, Restock: *2006 – August 2007*

- Stock management, Zoning, cleaning, maintaining merchandise PDA scanner training and experience

Activities:

IEEE - Member
Tau Beta Pi (National Engineering Honor Society) – Member

Elias Carrasco

elias.carrasco@hotmail.com

OBJECTIVE: A full time position in a hardware design, verification, or modeling.

EDUCATION:

AS, Computer Science, Folsom Lake College
In progress BS, Computer Engineering, CSU Sacramento: May 2017
Current GPA 3.61

Related Courses:

- Microcomputers and Assembly Lang.
- Advanced Computer Organization
- CMOS and VLSI
- Operating Systems Pragmatics
- Robotics

WORK EXPERIENCE:

Software Development Intern - Intel: Working with modeling software to find a new workflow for HLS to design, test, and verify IPs rapidly. Modeling i486 processor, then feeding it the instructions to calculate digits of pi. Then putting it down to the FPGA level, and retrieving the output with hardware and software transactors.

PROJECT EXPERIENCE:

Continuous Passive Motion Device (CPM): Implement a device that will help knee rehabilitation patients recover more quickly without the need to always be laying down. This group project was done in three phases. First, we identified a potential issue in the field. Next, we planned out the design by setting up a project timeline and then executed the work packages. Finally, we came back and iterated on the design, adding additional features.

Limited Microprocessor Design: In a group of two, we worked to design a pipelined CPU in three phases. First the design, then merging, and lastly removing redundancies.

Robo Matter: This is a CNC used to cut frames for pictures. The goal was to modernize the machine with a Raspberry Pi and repair the hardware. Unfortunately, it did not pan out as the controllers I had couldn't supply enough current to drive the motor and the blade.

RELATED SKILLS

Communication/Organization Skills

- Methodical way of solving problems
- Excellent book-keeping
- Supportive Team Leader
- Not afraid to ask questions

Computer Skills

Programming Languages: • C • C++ • Java • Python • Verilog • VHDL • SystemC • BlueSpec System Verilog

Operating Systems: • Windows • Linux • Raspbian(Raspberry Pi)

Software: • Visual Studio • Eclipse • PSpice • Xilinx ISE •AutoIt •CoFluent •CtoS

ACCOMPLISHMENTS AND ACTIVITIES

Member of ACM
3D-Printing
Member of Tau Beta Pi
Volunteer Firefighter