Project Document

Group #14

Electrical System for Exoskeletal Arm

Department of Electrical Engineering and Computer Science
University of Central Florida
Dr. Lei Wei
Senior Design I

Group Member	**Major**
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Abstract:

Limbitless Solutions is a non-profit organization that produces biomedical applications at low cost for patients throughout the country. Last semester, a team of Mechanical Engineering students at University of Central Florida decided to undertake an ambitious project that, with the help of Limbitless Solutions' resources, that may impact the biomedical community and even society as a whole. Their idea consists of an exoskeleton arm that can be applied to the upper limb of a patient with reduced, or non-existing mobility. The arm will operate on 3 degrees of freedom along artificial joints that will simulate their biological counterparts. When the patient applies any minimal force by contracting muscles in the arm, the exoskeleton will read the bio-electrical signals originated by the muscle contraction by means of EMGs, and produce movement. Electrical readings from the muscle will be processed by a control unit that will determine where to redirect the power. This power will then be used to actuate the mechanical joints. A hybrid design of pneumatic-powered actuators and direct drive motors will be used to create enough force to assist the patient with arm mobility. A feedback-controlled system will be set in place to allow the patient for unhindered movement of the articulations, while ensuring the safety of the user. What makes this exoskeleton arm special in comparison to its previous counterparts is that it will be produced at a cheaper rate than that of its average production cost. Although the Mechanical Engineering students, also known as the Rugschild Team, have developed the framework for the mechanical subsystem and researched into the electrical implications of the exoskeleton, the electrical system as a whole is of a complex nature. Motivated by the desire to provide a functional prototype by the end of the year, Group 14 has been assigned with the task of developing the electrical design of the exoskeleton arm, responsible for taking a muscle input via EMG, and producing a desired output signal to operate the actuators.

Exoskeleton Concept:

Engineering Requirements Table:

End-User Requirement #	Engineering Requirement #	Engineering Requirement
1	**1.1**	The system shall provide a fail-safe feature in case of emergency
1	**1.2**	The system shall not exceed a temperature of 80 °C
1	**1.3**	The power subsystem shall not compromise the user's safety in case of hazard
2	**2.1**	The system shall be able to adjust its input signal detection criteria in a user-by-user basis
2	**2.2**	The system shall have a response time no longer than 10 ms
3	**3.1**	The setup of the system shall not exceed 2 minutes
3	**3.2**	The system shall be able to shut down after exoskeleton reaches a position that makes arm easy to remove
4	**4.1**	The system shall allow exoskeleton arm to be used for a period longer than 9 hours, based on average use
5	**5.1**	The system shall allow the user to reset the controls to their initial state in case a deadlock occurs

End-User Requirements Table:

Req. #	End-User Requirement Statement
1	**The system shall not jeopardize user's safety**
2	**The system shall provide a fast response time to simulate human motion**
3	**The system shall be easy to install and remove**
4	**The system shall be durable to adapt to human lifestyle**
5	**The system shall be stable**

Requirement Concepts:

This system is to be designed to meet end-user expectations; our end-user is the team that will design the mechanical framework for the exoskeleton. Group 14 has carefully chosen some general constraints that apply to the electrical scope of this system and are essential in providing a product that is compatible with the mechanical system's goals. These end-user requirements are listed as follows:

1. **The system shall not jeopardize user's safety.** As with any technological applications that involve human interaction, the interacting device must guarantee human safety at all times. For the project's purpose, temperature and controls must be considered. The electrical framework should neither allow itself to become overheated nor attempt to manipulate arm past a pressure range, so as to prevent hazard to human safety. Additionally, if the arm's control system were to become unstable to where the user's integrity might be compromised, the system should be able to cease all operations by disconnecting the arm's power supply in a safe and accessible manner.
2. **The system shall provide a fast response time to simulate human motion.** The main goal of the exoskeleton arm is to provide the ability to operate the equipment under seamless motion, as opposed to their more digital, robotic counterparts. It was determined by the mechanical team that the response time between input and output should not exceed 10 milliseconds.
3. **The system shall be easy to install and remove.** For ease of installation and removal, the current design should be as efficient as possible. Calibration procedures and controls' initialization are established to be set up under 2 minutes. Also, controls will manipulate arm to be relaxed upon shutdown, so that it can be removed easily from the user.
4. **The system shall be durable to adapt to human lifestyle.** The main goal for the exoskeleton arm system as a whole is to be used as an extension of the patient. By extension, its power system should allow arm to work harmoniously with day to day tasks. For this reason, a constraint of 9 hours was considered optimal, given a working day.
5. **The system shall be stable.** In other words, the system must handle undesired outputs. Although not necessarily unsafe, these undesired outputs will decrease the user's fidelity toward the exoskeleton arm. Under certain muscle movements, it is possible that the arm might mix the inputs and output incorrect movement controls. To solvent this possible scenario, the system will have to feedback the output and ensure error correction so that the proper controls are applied. Additionally, if the controls were to lock into an unresponsive state from which they cannot exit, the controls should be able to allow the arm to restart into an initial state and resume normal operations.

House of Quality Diagram

Engineering Requirements

↑ = Positive Correlation
X = Independence
↓ = Negative Correlation

End-User Requirements		1.1) Fail-Safe Features	1.2) Operational Temperature	1.3) Battery Hazard	2.1) Flexible Calibration	2.2) Response Time	3.1) Setup Time	3.2) Easiness of Removal	4.1) Average Use	5.1) Easiness to Reset the System
		+	-	-	+	-	-	+	+	+
1) Safety	+	↑	↑	↑	X	X	X	↑	↓	↑
2) Responsiveness	+	X	X	X	↑	↑	↑	X	↓	↑
3) Easy Installation and Removal	+	↑	X	X	↑	↑	↑	↑	↓	X
4) Durability	+	X	↑	↑	↓	↓	↑	↑	↑	X
5) Stability	+	X	↑	X	↑	↑	X	X	↓	↑

Correlation Between Requirements

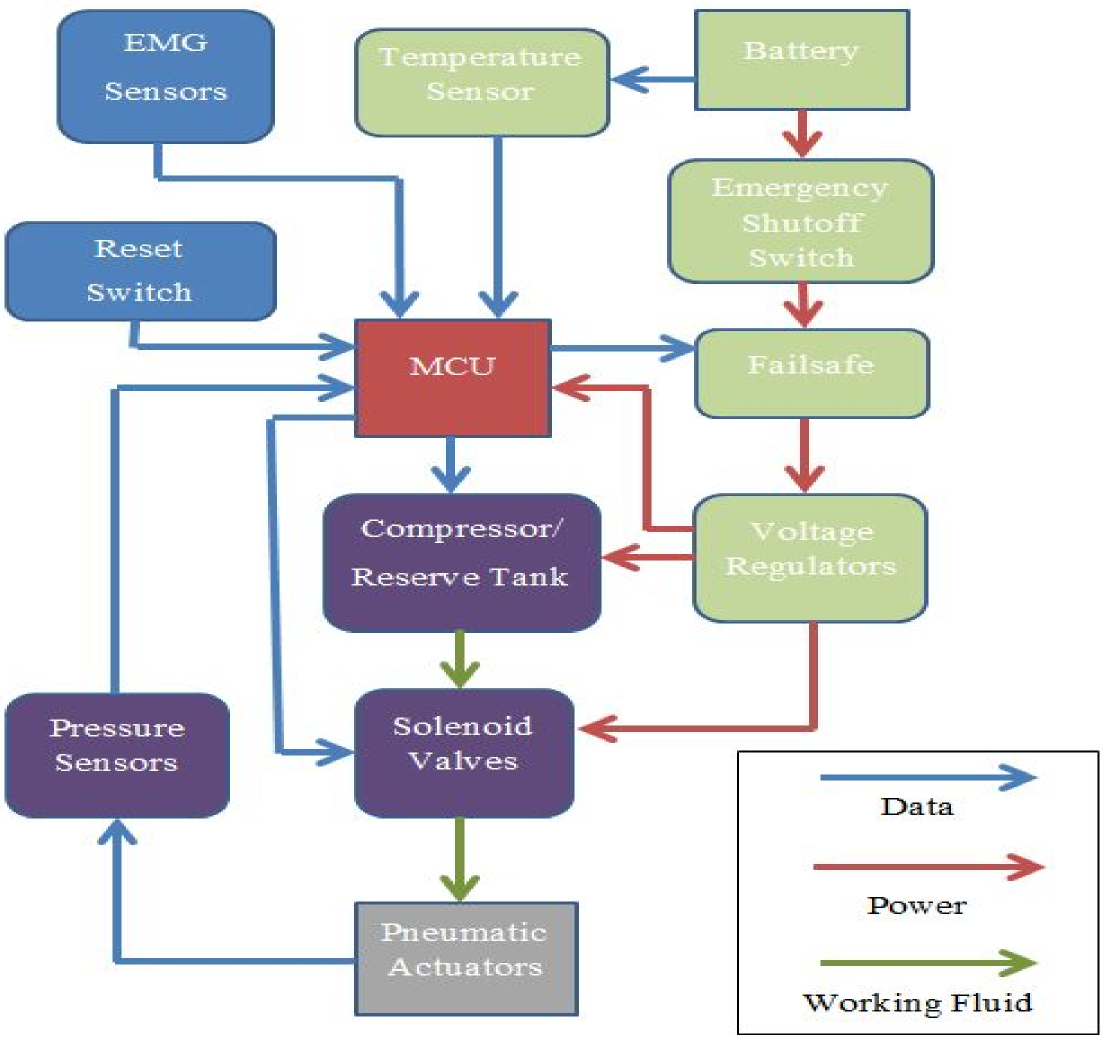
System Roles:

Based on design specifications and each member's technical skillset, Group 14 has decided to break down the project into four sections as follows.

Member	**Role**
Daniel Reveron	Systems and Control Lead
Kelvin Feliciano	Hardware and Power Lead
Brandon Johnson	Software Lead
Gavin Bell	Electrical/Mechanical Interface Lead

Legend for Block Diagrams:

Hardware Block Diagram:



Electro/Mechanical Design:

The design for the electro/mechanical portion of the exoskeletal arm is mainly comprised of four elements which will dictate the locomotion of the pneumatic actuators. The four elements allowing for movement of the actuators are: the compressor/reserve tank, the pressurizing solenoid valves, the vent solenoid valves, and the pressure sensors. The pneumatic actuators translate the pressure of the working fluid, in this case air, into the desired movement. To create the air pressure required to drive the system, there will be a compressor/reserve tank component. The compressor will need the reserve tank to allow for quick movements, reserving a large enough volume for the compressor to be able to keep up with constant movements all while maintaining a pressure adequately above that which is required. The pressurizing and vent solenoid valves will be used to control the flow of air to manipulate different actuators. It is the pressure sensors which will provide feedback ensuring the actuators are at the correct pressure correlating to their desired position.

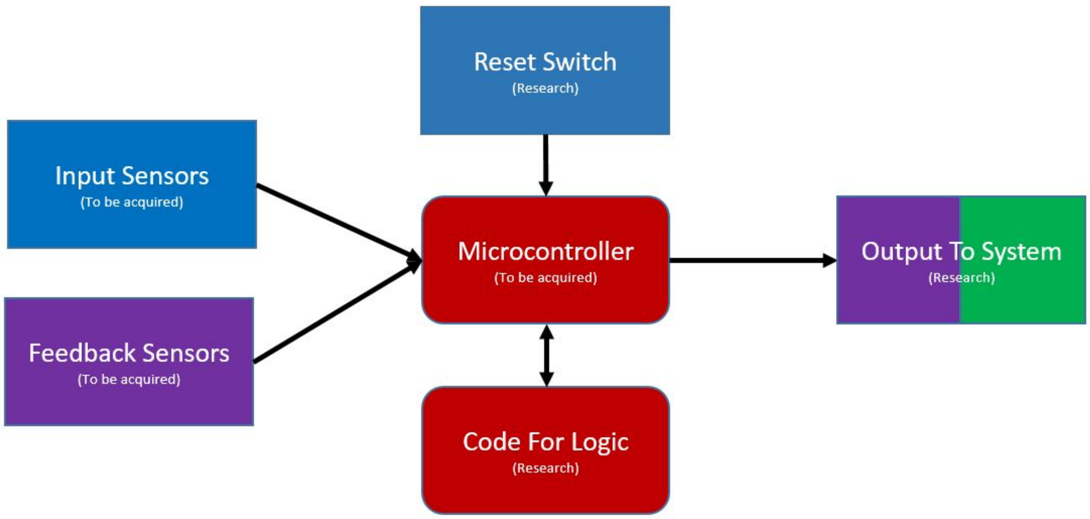
Hardware Design:

The exoskeleton will have a lithium battery that will power the system for approximately nine hours. The life of the battery will depend on how much and how long the arm is being used. We will set multiple safety features in place; to protect the battery from overheating, a temperature sensor will be installed to determine if the battery is operating at a safe range; if not, the system will shutdown. Another safety measure to be installed in the system an emergency shutoff switch that could easily be flipped manually by the user. Lastly, the system will need to operate in a certain psi range. If the sensor is reading a pressure that might be dangerous to the user's integrity, a trigger would deactivate the device.

This design will have multiple Electromyography Sensors (EMG). These are used for diagnostic procedures to assess the health of muscles and the nerve cells that control motor neurons. In this project, EMG sensors are intended to measure electrical response to a muscle contraction by nerve stimulation. The sensors will be attached in specific parts of the muscles, where the signal is strong and clear. In some patients, the signal might not be strong enough; to amplify the signal, additional hardware might be necessary. Additionally, a stronger muscle can be selected from another part of the body to capture the signal. To prevent picking up noisy signals, the channels will have to be as short as possible.

There are also some ideas regarding operation of the compact air compressor. It will likely be connected directly to the battery with a fuse for overcurrent protection. Also, it is worthy to consider that actuators have an in-rush current and any feedback from the motor could potentially affect any of the electrical components in the PCB; therefore, electrical solenoid valves on the actuators will be equipped with a diode to prevent any feedback when the coils collapse.

Software Block Diagram:



SW Design:

The basis of the software design is as shown above. The related components include the input sensors, the feedback sensors, the reset switch, the system outputs, the microcontroller, and the code. The idea is to use a sufficiently powerful microcontroller as a central control unit for the entire system. This microcontroller will need to have a large amount of pins to support the various inputs and amounts the system requires and will also need to have a high sampling frequency for good response time. Another good feature would be ease of peripheral addition and removal in case we want to temporarily attach things for testing purposes. Ideally, we will use an Arduino controller with an ATmega series chip for these reasons. The controller will first take inputs from the sensors and then process the code that will convert these inputs into appropriate system outputs. It will also connect to the reset switch, which if activated, should trigger a hard reset of the system. The feedback sensors will also need to be processed. Information from these sensors will be factored into the logic and will adjust the behavior of system.

Design Specifications:

- Microcontroller Unit
- PCB
- EMG Sensors
- Pressure Sensors
- Compressor
- Solenoid Valve
- Battery
- Temperature Sensor
- Voltage Regulator
- Switch

Estimated Budget:

Sponsor:			**Limbitless Solutions**
Component:	**Estimated Quantity:**	**Cost:**	**Total Cost:**
Microcontroller Unit	**1**	**$50.00**	**$50.00**
PCB	**1**	**$30.00**	**$30.00**
EMG Sensor	**8**	**$40.00**	**$320.00**
Electrodes	**8**	**$0.30**	**$2.40**
Pressure Sensor	**13**	**$10.00**	**$130.00**
Compressor	**1**	**$300.00**	**$300.00**
Solenoid Valve	**13**	**$15.00**	**$195.00**
Battery	**1**	**$100.00**	**$100.00**
Temperature Sensor	**1**	**$5.00**	**$5.00**
Voltage Regulator	**2**	**$10.00**	**$20.00**
Switch	**1**	**$7.00**	**$7.00**
Total Cost:			**$1,150.00**
Total Cost With 50% Contingency:			**$1,725.00**

Milestones:

Description	Weeks	Soft Deadline
Senior Design I		
Project Introduction & Group Formation	Week 1	5/20/16
Determine Project Idea	Week 2	5/26/16
Initial Proposal	Week 3	**6/3/2016**
System Design Review with Mechanical Team	Week 3 - Week 5	6/17/2016
Research Input Sensors & Feedback Sensors	Week 4 - Week 5	6/17/2016
Research Power Requirements	Week 4 - Week 5	6/17/2016
Research Printed Circuited Board Design	Week 4 - Week 5	6/17/2016
Research Microcontroller	Week 4 - Week 5	6/17/2016
Begin Design Paper and Continue Research	Week 6 - Week 8	7/8/2016
Generate and Turn in Table of Contents	Week 7	**7/1/2016**
Design Models/Input Test and Continue Design Paper	Week 7 - Week 9	7/15/2016
Turn in Current Draft of Senior Design Documentation	Week 8	**7/8/2016**
Finalize Paper and Begin Ordering Parts	Week 9 - 11	7/29/2016
Submit Final Document	Week 12	**8/2/2016**
Input Testing on Patient to Calibrate Electronics	Week 12 - Break	8/12/2016
Small Break Before Fall Classes		
Senior Design II		
Regroup and Discuss Plans	Week 1	8/26/2016
Gather All Parts and Finalize Design	Week 2 - Week 3	9/9/2016
Prototype System	Week 4 - Week 8	10/14/2016
Test and Debug system. Begin Final Documents	Week 9 - Week 11	11/4/2016

Integrate with Mechanical Team and Test	Week 11 to 14	11/25/2016
Final Presentation/ Evaluation	Week 15	12/1/16

Milestones(Detailed):

Senior Design I

Project Introduction & Group Formation	Week 1	5/20/16
A clear idea of what the course contains and what is expected of the class will be obtained. Working group will be drafted by students. Individuals' strengths and weaknesses will be defined within the group for design roles. Contact information will be exchanged. <u>Entire Team</u> ❏ 5/17 Start forming group ❏ 5/19 Finalize groupmates ❏ 5/19 Know individual strengths and weaknesses ❏ 5/19 Exchange contact information ❏ 5/20 Understand what the class is about ❏ 5/20 Submit Individual Project Idea assignment		

Determine Project Idea	Week 2	5/27/16
Project idea will be decided based on each member's input. This will be needed in order to write preliminary documentation. <u>Entire Team</u> ❏ 5/24 Team meeting ❏ 5/26 Brainstorm ideas ❏ 5/27 Decide on idea		

Initial Proposal	Week 3	**6/3/2016**
The initial document will be provided in accordance with the provided rubric. It is to be submitted by 12pm on 6/3. Before writing, details of project will be discussed. <u>Entire Team</u> ❏ 5/28 Decide roles ❏ 5/28 Team meeting with mechanical liaison ❏ 5/31 Meet with Limbitless Solutions		

❏ 5/31 Start writing Initial Proposal ❏ 6/2 Finalize document ❏ 6/3 Submit Initial Proposal by 12pm

System Design Review with Mechanical Team	Week 3 - Week 5	6/17/2016
Discussions will be held with mechanical team. System functionality will be known as well as constraints. By the end of this phase, design idea should be clear. <u>Entire Team</u> ❏ 6/7 Meet with Limbitless Solutions ❏ 6/11 Meeting with mechanical team liaison ❏ 6/14 Submit updated initial document by 10am ❏ 6/17 Should have full details from mechanical team of what needs to be accounted for <u>Daniel</u> ❏ 6/15 Bill of Testing Materials to be provided to Limbitless Solutions for research purposes and funding ❏ 6/16 Discuss extent of requirements with mechanical team and Limbitless Solutions		

Research Input Sensors & Feedback Sensors	Week 4 - Week 5	6/17/2016
Research will be done to understand how input is provided to control system. Test scenarios to be developed at a high level with mechanical team liaison in order to carry out with patient. More information on feedback sensors will be acquired <u>Gavin</u> ❏ 6/16 Contact mechanical team lead to discuss feedback sensor ❏ 6/17 Determine feedback system design at a high level ❏ 6/17 Acquire EMG sensor for testing <u>Daniel</u> ❏ 6/17 Understand how signals are retrieved from muscles and EMG functionality ❏ 6/17 Develop input test plan for patient		

Research Power Requirements	Week 4 - Week 5	6/17/2016
<u>Kelvin</u> ❏ 6/15 Contact mechanical team to discuss DC motors and pneumatic actuators ❏ 6/16 Research batteries suitable for the system ❏ 6/17 Select the battery that will power the control system		

Research Printed Circuited Board Design	Week 4 - Week 5	6/17/2016
<u>Kelvin</u> ❏ 6/16 Getting Familiar with the software to create electrical and PCB schematic ❏ 6/17 Research and review companies that provide PCB service		

Research Microcontroller	Week 4 - Week 5	6/17/2016
Research will be done for microcontroller setup and codebase. This will be the logic control for the system so much effort needs to go into understanding this process. <u>Brandon</u> ❏ 6/7 Decide what controller will be used ❏ 6/8 Decide coding language and download IDE ❏ 6/12 Research the hardware of the controller (# of pins, chip, available peripherals) ❏ 6/17 Learn basic syntax of the controller in chosen language (Should be able to at least flash an LED)		

Begin Design Paper and Continue Research	Week 6 - Week 8	7/8/2016
Research efforts will be continued for the scope of this project. A final design paper will start to take form as a draft. <u>Entire Team</u> ❏ 6/21 Have Final Paper Started ❏ 6/28 Have at least 10 pages worth of documentation each (Not including this document). <u>Brandon</u> ❏ 6/24 Be familiar with more complicated code for controller ❏ 7/8 Be completely comfortable with the code base and be able to develop real projects <u>Daniel</u> ❏ 6/21 Obtain finalized test plan for input testing ❏ 6/21 Meeting with mechanical team to discuss integration ❏ 7/1 Finalize requirements' statement <u>Gavin</u> ❏ 6/24 Create Mechanical system overview design schematic ❏ 7/1 Create outline for mechanical system actuation		

Kelvin ❏ 6/20 Obtain specifications of electrical components ❏ 6/26 Develop circuit design ❏ 7/1 Simulate circuits on electrical design software

Generate and Turn in Table of Contents	Week 7	**7/1/2016**
Table of contents will be submitted based on what has been done on the document so far. Entire Team ❏ 6/28 Have all pieces of document (so far) combined ❏ 6/30 Have table of contents generated ❏ 7/1 Turn in Table of contents by 12pm		

Design Models/Input Test and Continue Design Paper	Week 7 - Week 9	7/15/2016
Models for the system will be designed and continued work will be done on the paper. Entire Team ❏ 7/6 Have at least 20 pages each (Not including this document). Brandon ❏ 7/8 Have pseudocode for test system ❏ 7/15 Have pseudocode for control system Daniel ❏ 7/2 Meet with team to discuss status ❏ 7/8 Testing procedures for the system to be fully documented in accordance with acquired requirements ❏ 7/15 Obtain budget from teammates to order parts for system implementation Gavin ❏ 7/8 Have circuit set up to measure EMG signals ❏ 7/15 Determine operating range of EMG signals and extent of sensor noise Kelvin ❏ 7/4 Begin integrating circuits in breadboard ❏ 7/8 Measure current, voltages, and compare to theoretical calculated values ❏ 7/12 Make necessary adjustments and retest ❏ 7/15 Finalize PCB Design		

Turn in Current Draft of Senior Design Documentation	Week 8	**7/8/2016**
Current draft of the design documentation will be turned in. <u>Entire Team</u> ❏ 7/7 Have current pieces of the document assembled ❏ 7/8 Turn in current draft of design paper by 12pm		

Finalize Paper and Begin Ordering Parts	Week 9 - 11	7/29/2016
Document will be finalized in preparation for submission. Parts will be ordered <u>Entire Team</u> ❏ 7/22 Have all pages of final design paper complete ❏ 7/24 Have complete list of required parts and vendors ❏ 7/26 Have document assembled and number of pages checked ❏ 7/29 Peer-review entire document and begin final edits ❏ 7/29 Have all parts ordered (including PCB)		

Submit Final Document	Week 12	**8/2/2016**
Final document for the course will be submitted. <u>Entire Team</u> ❏ 7/31 Have entire paper completely finished ❏ 8/2 Submit paper by 12pm		

Input testing on patient to calibrate electronics	Week 12 - Break	8/12/2016
Sensor testing must be done on the patient (to be monitored by faculty or Limbitless) to obtain readings and develop thresholds for the arm. <u>Entire Team</u> ❏ 8/12 Have completed input testing on patient ❏ 8/12 Have all required data for thresholds		

Small Break Before Fall Classes		

Senior Design II

Regroup and Discuss Plans	Week 1	08/26/2016
We will regroup and go over a detailed plan of how the semester should go. This is important to start the semester on a good foot. <u>Entire Team</u> ❏ 8/22 Discuss new schedules and availability ❏ 8/26 Have discussed any problems that have come up so far ❏ 8/26 Have a detailed plan of the semester		

Gather All Parts and Finalize Design	Week 2 - Week 3	9/9/2016
We will need to determine what parts we have and set everything in stone to start building our final prototype. <u>Entire Team</u> ❏ 8/31 Perform check of inventory to determine what we are missing ❏ 9/2 Discuss final design as a team and adjust if necessary ❏ 9/7 Perform second inventory check. All pieces should be in (hopefully) <u>Brandon</u> ❏ 8/31 Have pseudocode adjusted for patient thresholds and specifications ❏ 9/9 Have primitive code mockup and adjust bad logic <u>Gavin</u> ❏ 8/31 Have first generation of hardware prototype in hand ❏ 9/9 Determine bugs in initial design <u>Daniel</u> ❏ 8/31 Assist teammates with subsystem testing ❏ 9/3 Coordinate integration testing with mechanical team <u>Kelvin</u> ❏ 8/31 Have schematic/wiring diagram completely revised ❏ 9/5 Verify all components and compare to specifications ❏ 9/9 PCB Tested		

Prototype System	Week 4 - Week 8	10/14/2016

We will build the prototype for the system. It is important that we get it done in this time so that we will have time to test and integrate with the actual arm from the mechanical team. <u>Entire Team</u> ❏ 10/7 Have all individual components complete ❏ 10/7 Start integrating parts of the system ❏ 10/14 Have prototype built <u>Brandon</u> ❏ 9/21 Controller should be able to at least read valid input and do simple processing ❏ 10/4 Controller should be able to convert input to output (even if unstable) ❏ 10/7 Have code complete and in working condition <u>Daniel</u> ❏ 10/13 Have designed method of demo in case mechanical team should fail ❏ 10/14 Order demo parts if necessary (to be evaluated by Gavin) <u>Gavin</u> ❏ 09/21 If revisions needed order the redesigned components ❏ 10/04 Test system using breadboard ❏ 10/07 Integrate the multiple sensors and actuators ❏ 10/13 Evaluate mechanical team's progress <u>Kelvin</u> ❏ 9/15 Have backup design for system to limit risk ❏ 10/3 Evaluate the pros and cons of different power sources. See if current design works. ❏ 10/7 Have power system built

Test and Debug system. Begin Final Documents	Week 9 - Week 11	11/4/2016
This is the time that we will debug and finalize our system. By the end of this, we should have an A worthy standalone project. We will also begin our final documentation. <u>Entire Team</u> ❏ 10/17 Start debugging system ❏ 10/28 Have operational system for base cases (Ok if edge cases need work) ❏ 10/28 Have final documentation started ❏ 11/4 Have completed electrical system ready for integration (or submission) <u>Brandon</u>		

- ❏ 10/17 Begin troubleshooting bugs
- ❏ 10/28 Optimize code if needed
- ❏ 11/4 Have bug free code

Gavin
- ❏ 10/17 Begin attempts to integrate system with mechanical team
- ❏ 10/28 Determine areas for change and adjust accordingly
- ❏ 10/28 Order any components needed for change
- ❏ 11/4 Debug and test available system with mechanical team

Kelvin
- ❏ 10/10 Measure current, voltages, and compare to theoretical calculated values
- ❏ 10/17 Make necessary adjustments
- ❏ 10/28 Have stable system

Integrate with Mechanical Team and Test	Week 11 to 14	11/25/2016

In this phase, we will integrate our design with the mechanical team and test it as a whole.

Entire Team
- ❏ 11/8 Know if integration with mechanical team will be feasible based on their progress
- ❏ 11/8 Continue to work on documentation
- ❏ 11/22 Have All documentation complete

Brandon
- ❏ 11/18 Adjust code as necessary

Gavin
- ❏ 11/8 Determine if project can be successfully combined with mechanical teams design

Daniel
- ❏ 11/11 Adjust requirements as necessary
- ❏ 11/18 Adjust testing plan as necessary

Kelvin
- ❏ 11/11 Determine that the system has enough power to run components efficiently
- ❏ 11/18 Relocated wiring if necessary for performance/aesthetics/easiness

With Integration
Entire Team
- ❏ 11/18 Have system integrated and begin debugging (if not started)
- ❏ 11/25 Have system fully integrated and stable

Gavin ❏ 11/11 If design can be successfully integrated, continue integration ❏ 11/18 Fully integrated system complete ❏ 11/25 Fine tune system **Without Integration** Entire Team ❏ 11/18 Have initial demo system setup and begin debugging ❏ 11/25 Have demo system fully working and stable Gavin ❏ 11/11 If Design cannot be fully integrated with mechanical team's design test rig for presentation ❏ 11/18 Build test rig ❏ 11/25 Fine tune system

Final Presentation/ Evaluation	Week 15	**12/1/16**
We will have a fully working and presentable demo. We will also have all of our documentation in order. We will make a final presentation to end the course. Entire Team ❏ 11/28 Make amendments to design paper based on final design ❏ 11/29 Have presentation rehearsed at least 3 times ❏ 11/29 Have demo ran through at least 3 times ❏ 12/1 Give demos ❏ 12/1 Give presentation		