



E-Bike and Wheelchair Motor Control Circuit

ECE 480 Team 9 for

Resource Center for Persons with Disabilities

Tyler Borysiak

Stephen Dunn

Myles Moore

Joshua Lamb

Alex Sklar

Dr. Virginia Ayres - Facilitator

Mr. Stephen Blosser - Sponsor

Final Proposal

Friday, October 9, 2015

Michigan State University

Executive Summary

Electric vehicles are in high demand around the world and especially in India as a low cost, high independence, rugged form of transport. Typically, they are powered through the use of a costly class of electric motor, the direct-current DC motor. To combat this problem, ECE 480 Team 9 proposes the use of an inexpensive automotive alternator that would replace the DC motor, providing higher efficiency and increased torque at wider ranges of speed. The proposed design makes use of a high-speed sensor that will measure the magnetic field produced by a uniquely polarized magnet. These have the ability to provide high resolution angle information to a microprocessor. With this data, the microprocessor holds the potential to increase efficiency of electric motors by applying precise power pulses at optimal positions within the motor as it rotates. By controlling the magnetic field, motor efficiency can be increased, the motor can be used for regenerative braking to recharge the battery and it can provide enhanced stopping performance.

Table of Contents

Motivation	Page 4
Summary of Benefits	Page 4
Motor Concepts	Page 5
Sensor Concepts	Page 6
Microcontroller Concepts	Page 7
Budget	Page 9
Project Management Plan	Page 10
References	Page 12

Motivation:

In a novel entrepreneurial enterprise, Dr. Pauliah and his sister Ms. Pauliah of the Sunrise Orphanage in Bobbili, India, are seeking a product that can be manufactured and sold to help support the orphanage and add a low-cost medical clinic to the existing facility. Michigan State University is affiliated with the Sunrise Orphanage and its future clinic through Asian Aid USA, a Christian nonprofit organization that is committed to making a difference in the lives of children and people in poverty. Asian Aid High School students in Jaipur, India learn electronic circuit design from Stephen Blosser, an Assistive Technology Specialist at the Resource Center for Persons with Disabilities. Mr. Blosser is an honorary ambassador volunteer with orphanages in the area and helps choose technology for the orphanage members to work with. He has designed an electric tricycle, which is in high demand in India and around the world. This tricycle could be manufactured by student employees such as those residing at the orphanage. Students at the orphanage sponsored by Asian Aid would benefit from the learning experience that the manufacture and sale of these tricycles would provide, as well as benefitting from the part-time employment.

Mr. Blosser's original design included the use of a DC motor to power the tricycle. The DC motor performed well, but it was too expensive to be viable for the proposed application. After researching alternatives, an automotive alternator was found to provide very similar functionality at much lower cost.

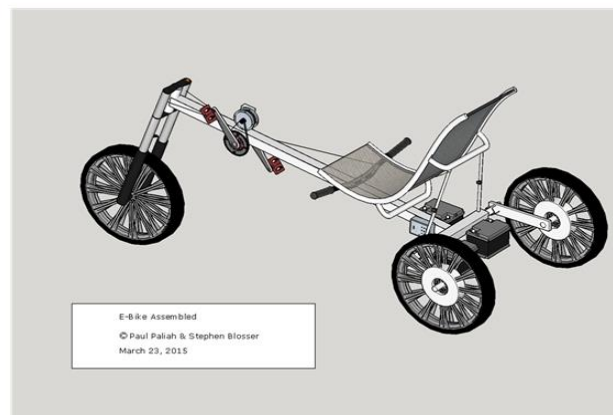


Figure 1. Concept e-Bike

Summary of Benefits:

Electric vehicles are in high demand around the world and especially in India as a low cost, high independence, rugged form of transport. Typically, they are powered through the use of a costly DC motor. To combat this problem, we

propose the use of an inexpensive automotive alternator that would replace the DC motor providing higher efficiency and increased torque at wider ranges of speed. The proposed design makes use of a high-speed sensor that will measure the magnetic field produced by a uniquely polarized magnet. These chips, with high resolution feedback, hold the potential to increase efficiency of motors by applying precise power pulses at optimal angles. By controlling the field, we can also enhance regenerative braking and stopping performance.

This design concept has the potential for use in other applications that require electric motors. The goal is to design a robust, efficient, and inexpensive motor that can be utilized in numerous other future products.

To accomplish the design goals required by the Sponsor, three key sub goal choices must be investigated: sensors, motor and microprocessor.

Motor Concepts:

We have chosen to use automotive alternators as the motors for this application. Alternatively, it would be possible to use DC brushless electric motors to accomplish the same task. These DC motors are typically highly efficient and require little to no complex hardware or software in order to operate. However, DC motors used in electric vehicle design are generally very expensive due to the large rare-earth magnets used in their construction. This fact has led our team to pursue the conversion of an automotive alternator to be used as a motor. This choice requires the development of more complex hardware and software in order to drive the unusual motor configuration,

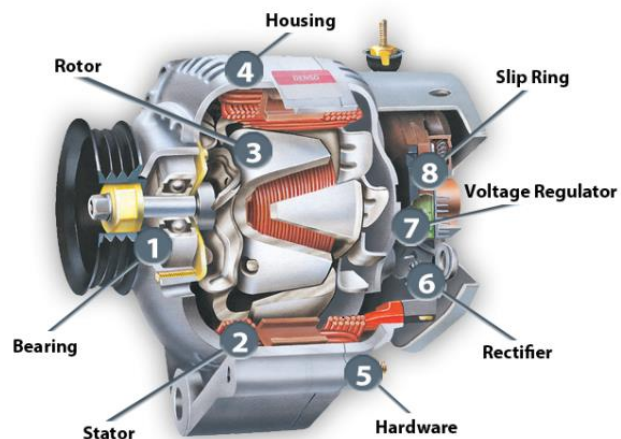


Figure 2. Automotive alternator with reconfigurable options: stator, rectifier and rotor.

but allows for cost savings that far outweigh the additional complexities. This cost advantage is one of the key design choices in this proposal.

The automotive alternators used in this design are of the hybrid-brushless variety, having no expensive, internal rare-earth permanent magnets. Instead, the motors require that a small amount of current be passed through brushes to a coil in the rotor in order to magnetize it. Current is then applied to the outer stator coils in order to induce an electromagnetic force to turn the rotor. The stator has 36 coils around its perimeter. The test alternators have 36 coils that are wired into 3 phases connected in a “delta” pattern such that each phase has 12 coils and each coil is separated by 10 degrees around the stator. The software algorithm and supporting hardware will need to be able to drive this motor configuration.

Sensor Concepts:

In order to effectively control the operation of the alternator running in a motor configuration, the absolute angle of the rotor shaft will need to be sensed at a high frequency. A hall effect-sensor for measuring the magnetic field of a spinning magnet provides a unique solution. The sensor is available either as a stand-alone electrical sensor or as part of an integrated chip with a common communication bus to connect to a microcontroller. The Avago AEAT-6600-T16 angular magnetic encoder is one solution with high resolution for measuring precise angles of the magnetic field as the magnet spins. This chip provides a complete solution with an integrated

communication interface, however the cost of \$8.04 per chip led to further research into finding a lower cost solution. The chip chosen to accomplish the task is the AS5132 Programmable High Speed Magnetic Rotary Encoder manufactured by AMS, which costs \$6.05 per chip. The AS5132 is also readily available pre-

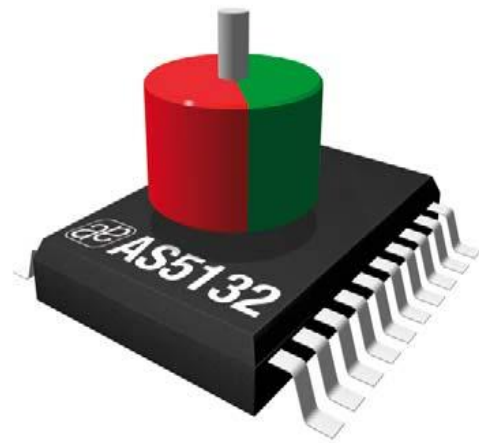


Figure 3. Hall Effect rotary position sensor and diametric magnet [4].

soldered to a computer board, which will decrease the time for development. The AS5132 is capable of sensing the absolute orientation of a nearby magnetic field and report the value in degrees between 0 and 359. The lower resolution should be sufficient at the expected rotational speeds. A small magnet will be affixed to the end of the rotor shaft and the chip will be placed directly over this magnet. This will allow the absolute position of the motor shaft to be known at any point in time. Additionally, the AS5132 is able to communicate over a synchronous serial interface allowing fast and precise communication of the angle of the motor shaft to the microcontroller.

The sensor must use a magnet that has a diametrical magnetization direction. This means that the magnet is magnetized across its diameter, with its north pole on the top semicircular half while the south-pole is at the bottom of the semicircular half.

In order to control the torque of the motor according to the desires of the rider, it will be necessary to have some a throttle that the user is able to turn in order to have the motor apply more or less torque through the drivetrain. For this task, a popular Hall-effect sensor based throttle meant for scooter applications is under consideration.

Microcontroller concepts:

Driving an automotive alternator as a motor requires the use of a microcontroller in order to collect sensor data and compute when and how to energize the rotor and stator coils. In order to support high-speed operation of the motor, the microcontroller needs to be able to operate quickly. It has been theorized that having a hardware floating point unit on the chip will greatly increase the speed of the control algorithms. Additionally, the microcontroller needs to be able to communicate directly with the throttle and AS5132 sensors as well as the

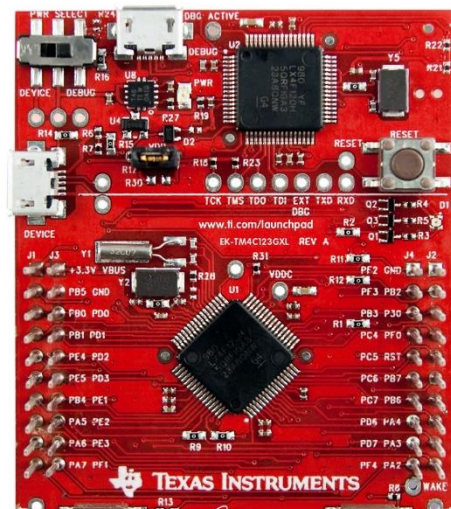


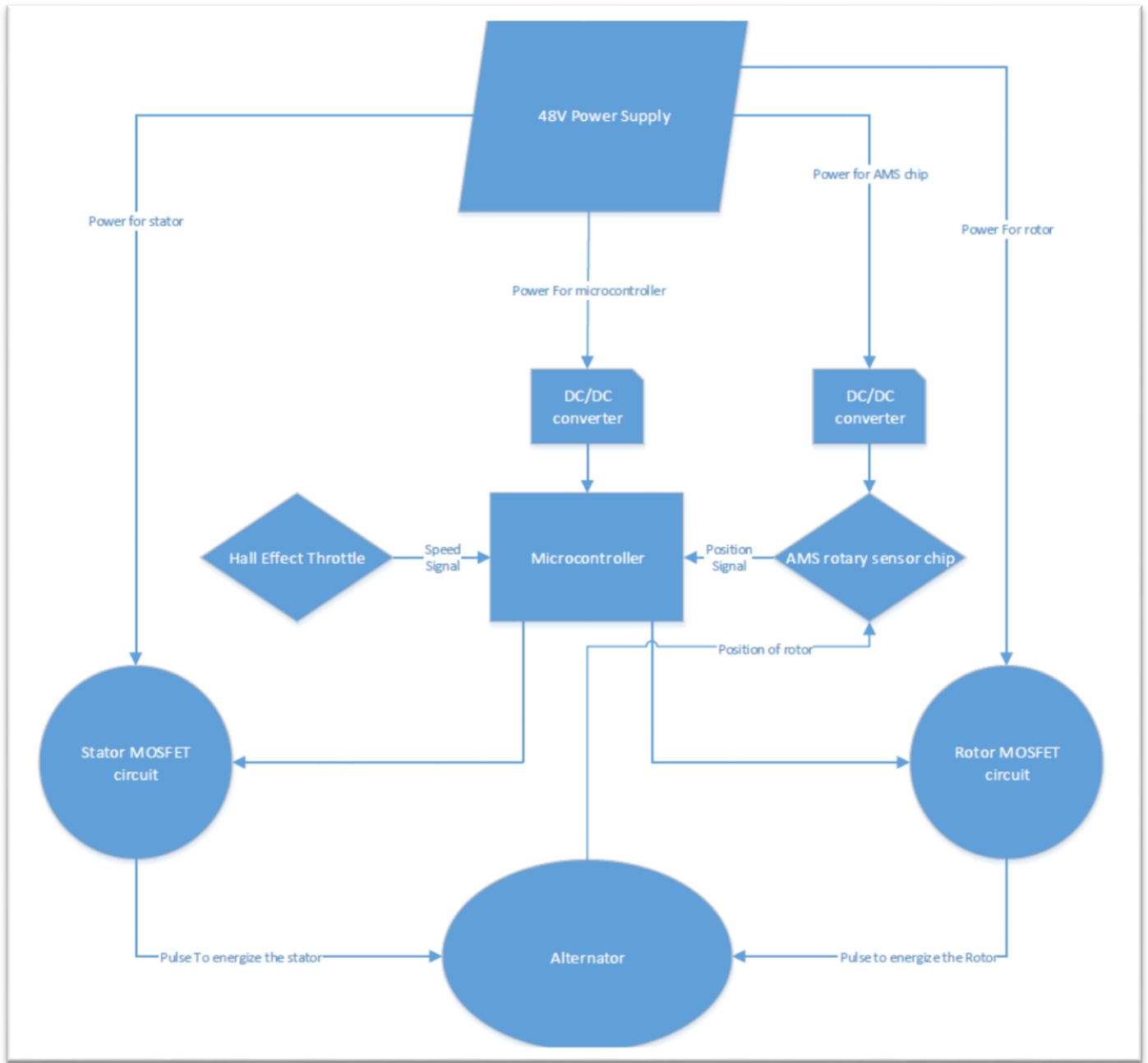
Figure 4. Texas Instruments development board for an ARM Cortex M4 microcontroller [5].

driver board for the stator coils. Finally, in order to facilitate rapid software development, a development board with integrated debugging capabilities will be required. For this task we have chosen the Tiva-C Series EK-TM4C123GXL development board from Texas Instruments. The microcontroller on the development board is the TM4C123GH6PM, which is expected to meet or exceed all of the required capabilities, operating at a maximum clock frequency of 80MHz and containing the previously mentioned floating point hardware. This microcontroller and the use of a development board is expected to ease the creation of the software algorithm.

Texas Instruments officially supports this board through two software packages, Energia and Code Composer. Energia is a lightweight development software with basic development features intended to allow the hobbyist to quickly unlock the capabilities of the hardware. However, it lacks many of the features of a full integrated development environment, such as debugging. Code Composer provides a more feature complete solution at the expense of some added complexity. However, for a software solution of the scale required for this project, Code Composer and the accompanying TivaWare software library for our development board are envisioned to provide us with the necessary tools to write a performant and efficient motor controller solution.

Conceptual Diagram:

The following is a high-level block diagram pertaining to the proposed design. The 48V power supply is the main source of power for the circuit. The microcontroller receives the speed input from a Hall-Effect throttle and a shaft position input from the AMS rotary sensor chip. This allows the microcontroller to control the current provided to the rotor and stator.



Risk Analysis:

Technical:

The alternator will require a high voltage, between 24 and 48 volts, and a high current, potentially higher than 50 amps. The circuit may use a lot of power which has the potential to cause a large amount of heat to be generated. This can lead to overheating and damage if the circuit is not cooled properly. Using under-rated components could increase the risk of circuit damage.

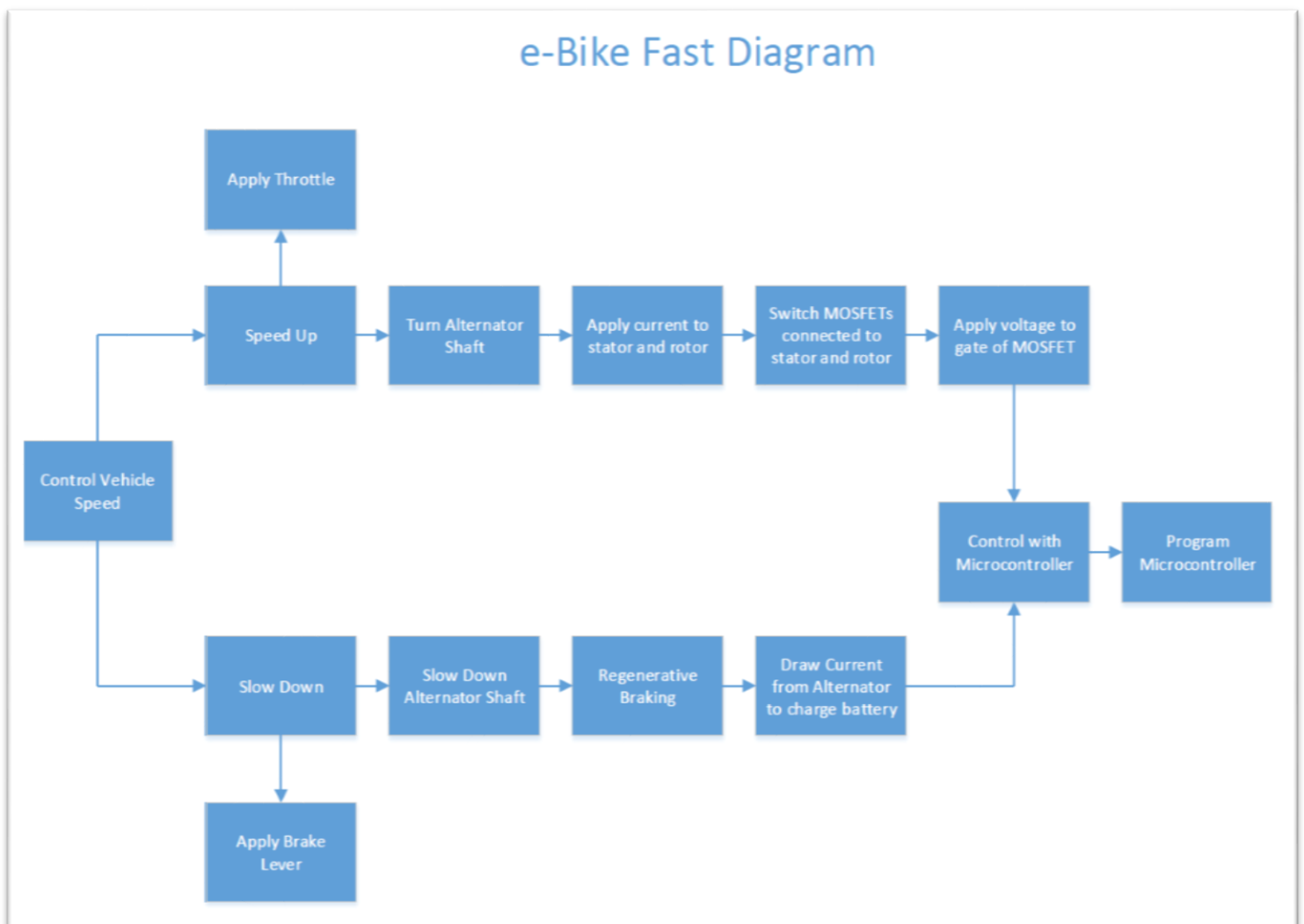
There is a small risk that the salvaged alternators proposed for this application may have been damaged (physically or electrically) in prior use, however many of the components likely to have failed will be replaced as a part of this proposed solution. Additionally, a proper battery management and protection system will be crucial to the final design in order to ensure the battery pack is operating within safe limits.

Financial:

There is good reason to believe the parts used in this proposed design can be acquired in bulk for a discounted price. Due to supply uncertainties, there is a small risk that production of the final design could be interrupted or the component costs may increase.

Fast Diagram:

The primary function of the automotive alternator design proposal is to control the vehicle's speed using a microcontroller to apply pulses at optimal angles. This is achieved by switching MOSFETs that are connected to both the stator and rotor windings. To apply torque and increase the speed, power is applied from the batteries to the stator coils in the proper sequence. To apply regenerative braking and slow down the vehicle, the stator coils will be connected to a rectifying circuit and the rotor will be energized using short pulses.



Budget:

One of the key constraints of this project is developing a design that is both highly efficient and cost effective. The most expensive portion of the project will be the automotive alternators, which cost around \$20 to \$30. The use of these alternators instead of brushless DC motors will save at least \$60 per motor. Like most of the parts that are required for this project, the automotive alternators were already provided to the team; therefore we will not track their cost in our \$500 budget. Additional parts that were needed include the diametrically magnetized magnet, the AMS AS5132 rotary sensor, and an external throttle.

Part Description	Quantity	Cost of Each Part	Shipping Cost Total	Total Cost with Shipping
¼' x ⅛' magnets	4	\$0.38	-----	-----
½' x ⅛' magnets	4	\$1.13	\$11.00	\$17.04
AMS AS5132 Adapter Board	4	\$16.12	\$8.08	\$72.56
Hall Effect Throttle	1	\$14.99	~\$5.00	\$19.99
MOSFET N-Ch 100V 100A	6	\$2.86	-----	-----
MOSFET P-Ch 100V 76A	6	\$4.59	~\$6.00	\$50.70
Total Cost (tentative)				\$160.29

Project Management Plan:

Gantt Chart:

The project timeline consists of seven main phases. These phases include project definition, research of new designs, development of conceptual designs, initial prototype preparation, initial testing, initial prototype construction, and final design construction.

Task Name	Duration	Start	Finish	Predecessors
Project Definition	5 days	Tue 9/15/15	Mon 9/21/15	
Team Introduction	1 day	Tue 9/15/15	Tue 9/15/15	
Understand Project at High Level	1 day	Wed 9/16/15	Wed 9/16/15	2
Meet with Facilitator	1 day	Thu 9/17/15	Thu 9/17/15	3
Meet with Sponsor	1 day	Thu 9/17/15	Thu 9/17/15	3
Brainstorm Early Ideas/ Discuss with Team	2 days	Fri 9/18/15	Mon 9/21/15	5
Definition Milestone	0 days	Mon 9/21/15	Mon 9/21/15	6
Research New Designs	5 days	Tue 9/22/15	Mon 9/28/15	7
Research Rotors, Stators, Alternators	5 days	Tue 9/22/15	Mon 9/28/15	7
Use of Alternators as a DC Motor	5 days	Tue 9/22/15	Mon 9/28/15	7
Research AMS rotary sensor	5 days	Tue 9/22/15	Mon 9/28/15	7
Research applicable microcontrollers	5 days	Tue 9/22/15	Mon 9/28/15	7
Research Milestone	0 days	Mon 9/28/15	Mon 9/28/15	12
Develop Conceptual Designs	7 days	Tue 9/29/15	Wed 10/7/15	13
Brainstorm Concepts	3 days	Tue 9/29/15	Thu 10/1/15	13
Pre-proposal Development	6 days	Sat 9/19/15	Fri 9/25/15	
Develop Evaluation Criteria	1 day	Fri 10/2/15	Fri 10/2/15	15
Develop Design Options	1 day	Fri 10/2/15	Fri 10/2/15	15
Evaluate Conceptual Designs	3 days	Mon 10/5/15	Wed 10/7/15	18
Select Best Design	0 days	Thu 10/8/15	Thu 10/8/15	19
Initial Prototype Preparation	6 days	Thu 10/8/15	Thu 10/15/15	20
Proposal Preparation	14 days	Fri 9/25/15	Wed 10/14/15	
Proposal Presentation	0 days	Thu 10/15/15	Thu 10/15/15	22
Select Microcontroller	1 day	Thu 10/8/15	Thu 10/8/15	20

Task Name	Duration	Start	Finish	Predecessors
Select Rotary Sensor	1 day	Thu 10/8/15	Thu 10/8/15	20
Early Block Diagram Development	1 day	Thu 10/8/15	Thu 10/8/15	20
Order Base Parts	3 days	Fri 10/9/15	Tue 10/13/15	25
Early Budget Calculations	2 days	Wed 10/14/15	Thu 10/15/15	27
Preparation for Initial Testing	2 days	Wed 10/14/15	Thu 10/15/15	27
Begin Initial Testing	0 days	Fri 10/16/15	Fri 10/16/15	29
Initial Testing	12 days	Fri 10/16/15	Sun 11/1/15	30
Prepare equipment and parts	1 day	Fri 10/16/15	Fri 10/16/15	30
Set up testing area	1 day	Sat 10/17/15	Sat 10/17/15	32
Run Initial Tests	7 days	Sun 10/18/15	Mon 10/26/15	33
Demo 1	3 days	Tue 10/20/15	Thu 10/22/15	33
Record and Evaluate Data	2 days	Tue 10/27/15	Wed 10/28/15	34
Analyze Test Results and Find Solutions	3 days	Thu 10/29/15	Sun 11/1/15	36
Prepare to Construct Prototype	0 days	Mon 11/2/15	Mon 11/2/15	37
Construct Initial Prototype	17 days	Mon 11/2/15	Tue 11/24/15	38
Final Report/Presentation Preparation	27 days	Mon 11/2/15	Tue 12/8/15	
Final Report/Presentation Complete	0 days	Wed 12/9/15	Wed 12/9/15	40
Finalize Hardware Solution	5 days	Mon 11/2/15	Fri 11/6/15	38
Finalize Software Solution	5 days	Mon 11/2/15	Fri 11/6/15	38
Hardware/Software Integration	5 days	Sat 11/7/15	Thu 11/12/15	43
Testing/Optimizing Efficiency	3 days	Fri 11/13/15	Tue 11/17/15	44
Implement any Minor Changes	5 days	Wed 11/18/15	Tue 11/24/15	45
Demo Project Prototype	0 days	Wed 11/25/15	Wed 11/25/15	46
Construct Final Design	12 days	Wed 11/25/15	Thu 12/10/15	47
Design PCB Layout	3 days	Wed 11/25/15	Fri 11/27/15	47
PCB Fabrication/Soldering	3 days	Sat 11/28/15	Tue 12/1/15	49
Testing/Assembly	3 days	Wed 12/2/15	Fri 12/4/15	50
Design Day Preparation	5 days	Sat 12/5/15	Thu 12/10/15	51
Design Day	0 days	Fri 12/11/15	Fri 12/11/15	52

Role Descriptions:

Hardware Specialists:

Responsible for designing the power MOSFET switching circuits, any necessary modifications to the rotor and stator, and the high-voltage power supply for the entire system. Additionally, these specialists will make sure that the whole system has proper electrical and thermal protection.

Tyler Borysiak – Project Manager

Responsible for managing the whole project and verifying that the project is produced on time, with quality, and at the lowest cost. Responsible for setting up the weekly meetings with the facilitator and sponsor.

Alex Sklar – Lab Coordinator

Responsible for ordering the necessary parts that are required for the MOSFET switching circuits. This involves finding the optimal parts required at the lowest cost. Additionally, Alex maintains the lab equipment and ensures proper adherence to the lab safety requirements.

Myles Moore – Document Preparation

Responsible for preparing all documents which includes the coordination, revision, and editing of all deliverables.

Software Specialists:

Responsible for implementing the motor control algorithm which will effectively interface with the AMS sensor, throttle sensor, and the power MOSFET switching circuits.

Stephen Dunn - Webmaster

Responsible for establishing and updating the website page for the design team which includes all related project information. The website will be the interface to the outside world.

Joshua Lamb – Presentation Preparation

Responsible for editing and preparing all presentations. Additionally, Joshua makes sure that all of the equipment works properly during each presentation.

References:

1. Asian Aid
<http://www.asianaid.org/projects?projectId=14>
2. Stephen Blosser
<https://www.rcpd.msu.edu/about/teamrcpd/stephen-blosser>
3. Avago AEAT-6600-T16
<http://www.avagotech.com/products/motion-control-encoders/magnetic-encoders/aeat-6600-t16>
4. AMS AS5132
<http://ams.com/eng/Products/Position-Sensors/Magnetic-Rotary-Position-Sensors/AS5132>
5. Texas Instruments TM4C123GXL
<http://www.ti.com/tool/ek-tm4c123gxl>
6. Texas Instruments TM4C123GH6PM
<http://www.ti.com/product/tm4c123gh6pm>
7. Texas Instruments Launchpad Software
<http://www.ti.com/ww/en/launchpad/software.html?DCMP=mcu-launchpad&HQS=launchpadsoftware>