Dual Motor Differential

Senior Design Project
Jack Baskin School of Engineering
University of California Santa Cruz
April 2012 Project Report & Proposal

Gregory Dreisen | Steven Lewis | Peter Turner

Gregory Dreisen
Computer Engineer
gdreisen@ucsc.edu

Steven Lewis
Electrical Engineer
splewis@ucsc.edu

Peter Turner
Electrical Engineer
pturner@ucsc.edu

Table of Contents

Description ………………………………………………………………………………Page 3

Motivation ………………………………………………………………………………Page 3

Technical Description ………………………………………………………………………………Page 4
Differential Controller
Load Controller
FOC/PI/SV-PWM schemes

Work in Progress. ………………………………………………………………………………Page 6

Major Challenges ………………………………………………………………………………Page 7
Solved
Yet to solve

Schedule and Division of Labor ………………………………………………………………………………Page 7
Gantt Chart
Critical Path

Acknowledgements ………………………………………………………………………………Page 9

Works Cited ………………………………………………………………………………Page 9

Description

In the interest of eliminating the mechanical differential from a vehicles' drive train, a controller is to be designed to manipulate individual motors at each driven wheel. The controller will be capable of adjusting the power delivered to each wheel automatically according to the changing load conditions. The focus of the project consists primarily of developing a high performance feedback system using load simulations and modeling through industry standard simulation tools such as Simulink. Once completed, the system will model the individual motor responses of dual motor front wheel drive vehicle. The final design will take in external variables representing steering, speed and road condition and adjust the individual drive motors in real time for optimal vehicle performance and safety.

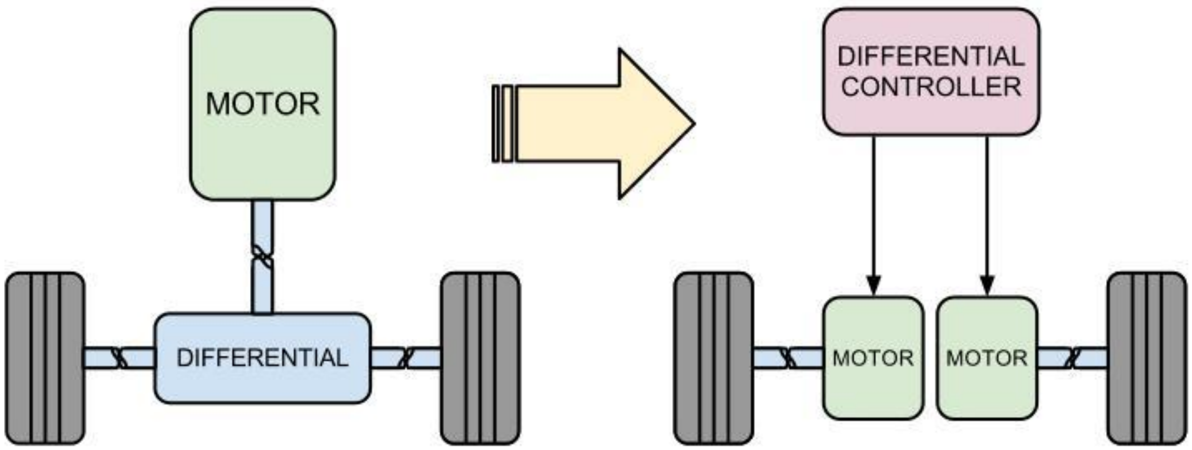


Figure One: Simplified model of a traditional mechanical differential and its replacement by the proposed dual motor differential system. Note that the drive shaft has been eliminated from the model and replaced with digital communications to each independent motor. This model suggests a real life vehicular implementation, but the model being proposed for this project will utilize an opposing load motors system to be discussed throughout this document.

Motivation

The limitations of mechanical automotive components often restrict designs from addressing key safety and functionality issues. In particular, the mechanical differential (which allows power transfer between two opposing drive wheels when loaded asymmetrically) often lacks the ability to adjust to the various load conditions a vehicle may endure. [7] An electronic dual motor drive will remove the need for a mechanical differential and provide more efficient control allowing for safer driving through improved traction response.

Increasing trends in environmental awareness combined with a dwindling supply of fossil fuels are kick-starting the electric vehicle market. Throughout this transition it is becoming increasingly important to replace old mechanical systems with more sophisticated electronic controllers-- this dual motor drive controller fulfills that need.

In a trade study it was discovered that such a controller is not available on the consumer market. [Attached, see Appendix] Even in the automotive industry, only Honda Motor Company has made public and notable developments as evidenced by the 2013 Acura NSX concept car. [1] Currently no torque vectoring dual motor drive vehicles are available to consumers, but testing is underway and it is clear that this emergent technology is ripe and ready for release and further development.

The proposed project benefits the participating engineering students in that it addresses a limitation in a developing field. The design of this controller will advance research and implementation methods of dual motor differentials, and also provide the participants with skills that will make them valuable assets in their pursuit of careers after graduating from the University of California Santa Cruz.

Technical Description

The Dual Motor Differential controller is to be implemented in three stages: 1) the throttle/input stage; 2) the differential controller stage; 3) the power stage;

1) The throttle/input stage takes user input to generate a control signal for motor speed and thus the forward motion of the vehicle. This may be generated by vehicle simulation software, or manually using software or hardware input mechanisms to manipulate variables in the load controller models[1]
2) The differential controller stage is a program written in Matlab/Simulink that takes the user input and generates the two three-phase pulse width modulation signals required to generate the rotating magnetic fields in the two motors. The controller must also take data from the outputs of the power stage to ensure proper speed maintenance in each motor, and to determine the load on each motor for calculations and adjustments necessary to maintain each motor individually.
3) The power stage is an H-bridge power amplifier for the three-phase pulse width modulation signals.

A load system is to be implemented, independent from the drive motor control scheme, which will simulate various vehicle, course, and road conditions. It will consist of two DC motors, each coupled to the shaft of its respective differential drive motor. These motors will apply a torque in the opposite direction of the applied torque generated from the differential controller. The load torque must be an accurate representation of the changing vehicle and road conditions, and thus must be generated from complex physical models. Vehicle simulation software will aid in the development of these models.

CarSim vehicle simulation software will assist in the generation of these complex vehicle models. The software is capable of importing and exporting over 800 vehicle characteristics in real time to dSPACE and Simulink for rapid prototyping and system manipulation on nearly 25 different vehicles. Adding this software component to the load controller system will ensure that the models being tested are accurate, thus narrowing the possibility of error accumulation in the experiment by limiting it to the differential controller being designed.

The broad scope of the project is depicted in figure two, showing the two independent control systems interactions with their associated motors. The diagram shows that both the three-phase motor and load motor are physically coupled together, but it is important to note that the feedback control mechanisms governing each device are independent of one another to emulate the separation of the *vehicle* from the *road*. Expansions of each of controller block can be seen in detail in figures three and four.

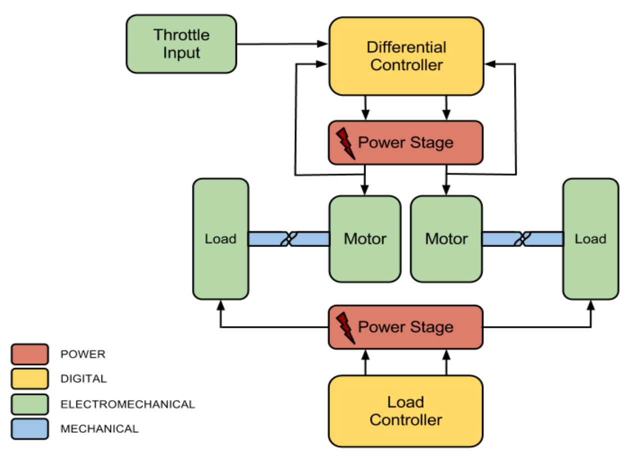


Figure Two: Basic system block diagram. Note that the differential controller block is isolated from the load controller block to emulate the separation of the *vehicle* under test, from the *road conditions* being simulated by the load. Each system has its own power stage to ensure independence.

[1] Note that the braking and steering inputs are not included in the input stage. This feedback system is designed to control the driving motors without input from a vehicles steering column or braking mechanism. The load controller, discussed later, will take user inputs for a vehicles braking/steering position to emulation those specified conditions in the load. The differential control will respond to appropriate turning/braking stimuli based on the loads sensed, not from direct vehicle input.

The components of the differential controller itself are abstracted in figure three. This controller must take the performance demand from the user and generate a control signal for the SV-PWM module (explained below), which will ultimately control the vehicle's speed. In order to ensure stability, the output of the drive motors will be measured in the FOC module (explained below) and fed back to the controller which will reconcile the control signal with the actual output. Common to both motors' feedback paths is a control circuit, denoted in figure three as the Differential Logic block, which will make decisions about the vehicle and road conditions based on the collective data gathered from both drive motors. This controller must be able to interpret various events as a turn or a loss of traction at one wheel, and generate control signals for the drive motors such that the simulated vehicle reacts favorably to these events.

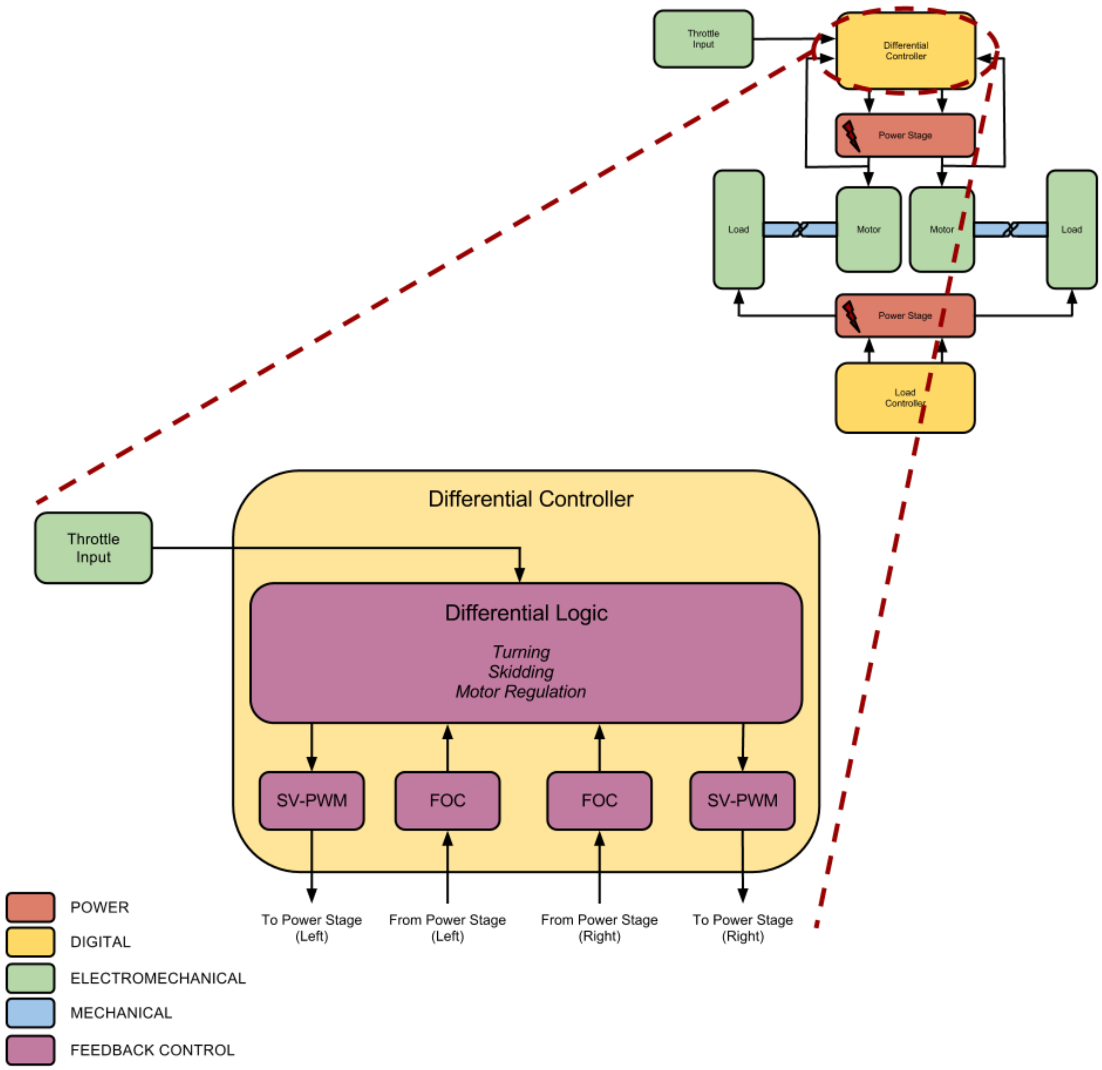
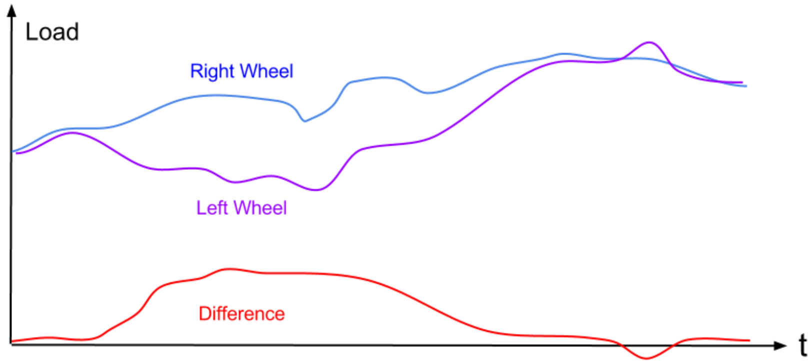


Figure Three: Expanded diagram of differential controller. The differential logic block shown is responsible for inferring the current state of the vehicle. Since it is important that the differential and load controllers remain isolated, steering, braking and other load data will never be given directly to the differential controller. Once the logic block has determined the conditions of the opposing loads on its drive motors, it will adjust the SV-PWM and FOC control algorithms to obtain the optimal drive performance.

In a turn, the load drops on one wheel and rises on the other. Due to the changing conditions of the road, the transients will appear noisy. By taking the difference between the two measurements, a turn should be recognizable as a non-zero average value over a pre-defined interval where the sign of that value determines the direction of the turn. This relationship between wheel loading and vehicle direction can be seen in figure four. The differential logic block will interpret this difference and assign an appropriate response depending on the slope of the difference.

Figure Four: Vehicle wheels under varying steering loads. The sign of the difference of each transient load signifies the vehicles current heading. The differential logic block will be responsible for reacting to these conditions and inferring if the vehicle is turning or slipping.

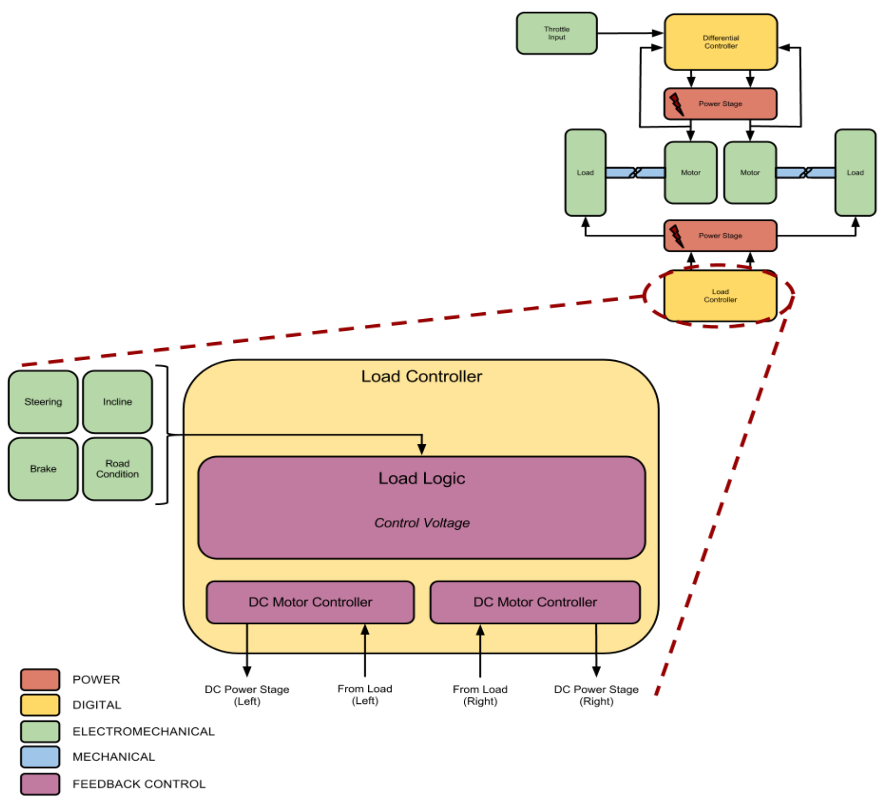


Space-Vector Pulse Width Modulation is a control scheme for driving H-bridges to generate an accurate three-phase sinusoidal control signal. By projecting the desired phasor voltage onto the corresponding axis, the proper H-bridge gates are switched on and off to create the desired output. [4] Other schemes exist for the generation of three-phase control signals, however, SV-PWM makes full use of the DC bus voltage, and can be easily implemented in software. [7]

Field-Oriented Control is a method of projecting dynamic phase current measurements into a rotating reference frame where torque is a time-invariant value. Using this, a three-phase AC motor can be controlled using a single variable for desired torque output. [7]

The load system (Figure Five) is to emulate different loads on the differential drive motors that will resemble real road and vehicle conditions. Since this is not the focus of the project, DC motors are chosen to simulate loads to reduce control complexity. Apart from the coupled motor shafts, note that this system is entirely separate from the differential controller. Using CarSim vehicle simulation software, the load motors will be able to dynamically simulate varying road conditions as they apply to different types of vehicles. The benefit of using the simulation software is that the loads will be accurate for modeling all the various suspension, weight balancing, tire traction and performance characteristics present in an actual vehicle. This will ensure accuracy in the differential controller by assuring that it is reacting to realistic conditions, and remove time spent developing a load model that is beyond the scope of the project.

Figure Five: Expanded diagram of load controller. Note that the steering, brake, incline and road conditions are inputs to the load logic block, not the differential controller. The load logic block will consist primarily of the CarSim vehicle simulation software to generate the appropriate motor responses as determined by the software. CarSim will export the motor data in real-time where it can be applied to the DC Motor controller blocks that will interpret the data and communicate directly with each load motor.



Work in Progress

As of March 13th 2012, the Baskin School of Engineering at University of California, Santa Cruz has provided a preliminary workstation for the orientation of team members to the development software and motor apparatuses, and research for control schemes.

Efforts have begun in order to acquire vehicle simulation software CarSim, which will be used to develop accurate models for the load simulation, and investigate the possibility of developing a real-time driving simulator for the Dual Motor Differential.

Current discussions focus on the control scheme for the decision engine in the feedback path of the differential controller, which interprets data from the output of the motor as specific driving and road conditions, then adjusts the torque demand accordingly.

Major Challenges

Solved

- Properly simulating a varying load on the three-phase motors went through several design revisions before realizing that an opposing load motor would be adequate.
- An obvious challenge was the acquisition of materials necessary to design and build the controller on a limited budget. After discovering that hardware and software from the Energy Conversion and Control course EE176 could be reused, members were able to begin discussing design options.
- It soon became apparent that obscene amounts of data are required to properly simulate a vehicle. Research on vehicle simulation software was completed to eliminate the need to capture field data. It was decided the CarSim mechanical vehicle simulation software would be the proper tool for eliminating the data collection component.

Not Solved

- A control system for the open-differential is still being researched prior to implementation. The attached works cited reflects some of this research, but models for the differential logic block of the controller have yet to be discussed in any significant detail.
- Much work remains to be done with the implementation of traction control and other handling considerations that will be added to the project after the open-differential is perfected. Proper responses to the multitude of driving situations that will need to be considered have not been enumerated, nor has the distinction been made as to how to tell the difference between each of this situations.
- Research must be done on the compatibility of CarSim simulation software with the dSPACE DS1104 hardware when performing real time analysis.
- Communication with a CarSim sales representatives has been established, revealing that an academic license is $4,200. With the prohibitive costs associated with this software, members are still seeking alternate ways of obtaining a temporary license for use throughout the project. Obtaining project sponsorship and contacting other Universities for a lent license are currently avenues being researched.

Schedule and Division of Labor

Schedule

The current Gantt Chart (Figure Six) is still fairly vague, especially towards the end of the project timeline. Once the initial phases of feedback control research are complete, it will become more clear where human resources will need to be allocated to complete the project in a timely manner. It is the intention of the group to revise the Gantt chart with additional detail to ensure that progress is timely and consistent.

Certain milestones must be completed along the critical path before we can add complexity to our controller. After an initial research period of the three relevant feedback control mechanisms has been completed, our first milestone is to create a controller that emulates an accurate load. After this is completed, both the differential controller and load controller blocks with be advanced. The differential controller will be enhanced with the capability to respond to varying traction and load conditions beyond that of a traditional open differential, and the load controller will be enhanced to interface with user inputs to generate certain conditions. These stages provide adequate time markers to ensure progress is consistent, and also ensure that in the event of extreme deviation from the schedule, the team will have achieved at least a portion of the milestones set-fourth.

Task Name	Duratic	Start	Finish
Research	**7 days**	**Sun 4/1/12**	**Sat 4/7/12**
Load Controller	**33 days**	**Mon 4/9/12**	**Fri 5/11/12**
CarSim Interface Study	3 days	Mon 4/9/12	Wed 4/11/12
Create Load Controller	**10 days**	**Fri 4/13/12**	**Sun 4/22/12**
DC Motor Control Scheme	1 day	Fri 4/13/12	Fri 4/13/12
Implement Physical Models	4 days	Sat 4/14/12	Tue 4/17/12
Interface with CarSim	5 days	Wed 4/18/12	Sun 4/22/12
Test & Revise	5 days	Mon 4/23/12	Fri 4/27/12
Differential Controller	**45 days**	**Sat 4/14/12**	**Mon 5/28/12**
Differential Control Scheme	3 days	Sat 4/14/12	Mon 4/16/12
Create Open Differential	**15 days**	**Wed 4/18/12**	**Wed 5/2/12**
Building	10 days	Wed 4/18/12	Fri 4/27/12
Test & Revise	5 days	Sat 4/28/12	Wed 5/2/12
Implementing Sophisticated Control Schemes	**15 days**	**Fri 5/4/12**	**Fri 5/18/12**
Traction Control	10 days	Fri 5/4/12	Sun 5/13/12
Super Handling	10 days	Fri 5/4/12	Sun 5/13/12
Test & Revise	5 days	Mon 5/14/12	Fri 5/18/12
Human Interfacing	**13 days**	**Sat 5/19/12**	**Thu 5/31/12**
Steering and Throttle Inputs	5 days	Sat 5/19/12	Wed 5/23/12
Control Desk GUI Design	5 days	Tue 5/22/12	Sat 5/26/12
Test & Revise	5 days	Sun 5/27/12	Thu 5/31/12
Document & Presentation Preparation	10 days	Fri 6/1/12	Sun 6/10/12
Buffer Time Allowance	10 days	Mon 6/11/12	Wed 6/20/12

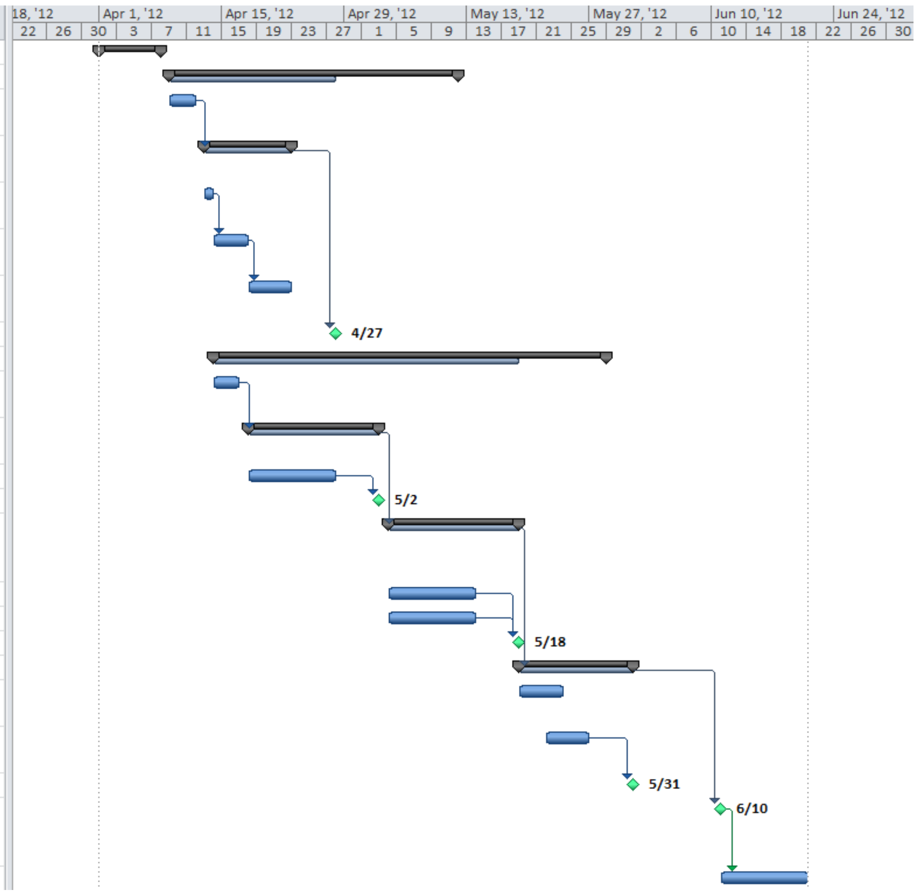


Figure Six: Gantt Chart Draft. Note the milestones in the chart are shown in an alternate color (green), evidencing that the team members have reached a new plateau of understanding. There is a 10-day allowance built in to the end of the timeline to allow for unplanned time expenditures.

Division of Labor

Peter Turner *Project Manager*

Responsible for overseeing the progress of the group as a whole and making sure that deadlines are met, ensuring that all group members have adequate support for their roles, and organizing inter-group meetings and meetings with outside sources.

Researcher and Programmer

Assigned area of expertise: field oriented motor control

Gregory Dreisen *Documentation Specialist*

Responsible for the compilation of research documents, data sheets and resources collected by the group to ensure proper citation and credit is always given. Proof reading documents, presentations and other media to be released from the group.

Researcher and Programmer

Assigned area of expertise: feedback control

Steven Lewis — *Treasurer*

Responsible for the oversight and documentation of purchases, and the allocation of funds to different sub-divisions of the project. If necessary, will also spearhead fundraising efforts and communications with donors, sponsors and investors.

Researcher and Programmer

Assigned areas of expertise: space vector modulation, physical/mathematical models

Acknowledgements

Faculty Mentors:

Stephen Petersen
Professor of Computer and Electrical Engineering
petersen@soe.ucsc.edu

John Vesecky
Professor of Computer and Electrical Engineering
vesecky@soe.ucsc.edu

Equipment Supplier:

Baskin Engineering UC SANTA CRUZ

Works Cited

[1] P. A. Einsenstein. (2011, March 3rd 2012). *Revolution on Wheels: Honda's New Hybrid SH-AWD System.* Available: http://www.thedetroitbureau.com/2011/12/revolution-on-wheels-honda%E2%80%99s-new-hybrid-sh-awd-system/

[2] A. Haddoun, M. E. H. Benbouzid, D. Diallo, R. Abdessemed, J. Ghouili, and K. Srairi, "Modeling, analysis, and neural network control of an EV electrical differential," *Ieee Transactions on Industrial Electronics,* vol. 55, pp. 2286-2294, Jun 2008.

[3] A. Kawamura, N. Hoshi, T. W. Kim, T. Yokoyama, and T. Kume, "Analysis of anti-directional-twin-rotary motor drive characteristics for electric vehicles," *Ieee Transactions on Industrial Electronics,* vol. 44, pp. 64-70, Feb 1997.

[4] J. W. Kolar, T. Friedli, J. Rodriguez, and P. W. Wheeler, "Review of Three-Phase PWM AC-AC Converter Topologies," *Ieee Transactions on Industrial Electronics,* vol. 58, pp. 4988-5006, Nov 2011.

[5] R. N. Miller, "Dual Motor Control," United States Patent, 1970.

[6] J. A. Santisteban and R. M. Stephan, "Vector control methods for induction machines: an overview," *IFAC Workshop on Control Education and Technology Transfer Issues. Postprint volume from the IFAC Workshop,* 01 1996.

[7] K. N. Spentzas and I. Alkhazali, "Generalisation of the concept of electronic differential," *Forschung Im Ingenieurwesen-Engineering Research,* vol. 66, pp. 273-278, Oct 2001.

[8] B. Tabbache, A. Kheloui, and M. E. H. Benbouzid, "An Adaptive Electric Differential for Electric Vehicles Motion Stabilization," *Ieee Transactions on Vehicular Technology,* vol. 60, pp. 104-110, Jan 2011.

[9] R. Vilanova and V. M. Alfaro, "Robust PID Control: An Overview," *Revista Iberoamericana De Automatica E Informatica Industrial,* vol. 8, pp. 141-158, Jul 2011.