Bradley University
Department of Electrical and Computer Engineering
Senior Capstone Project
Active Suspension System (ACTSS)

Xander Serrurier, Josh Rose, Chase Ramseyer, Rhydon Vassay
Project Advisor: Steven Gutschlag

December 8, 2016

Table of Contents

Introduction

For this project we are creating an active suspension system. This system will respond to rough terrain in real time to ensure a smooth ride for passengers. This is achieved by using a linear actuator to adjust the height of a mass relative to the rest of the system. Any vertical displacement due to external disturbances, such as bumps in a road while a car is traveling, will be attenuated. From its perspective, the vertical position of the mass will move a negligible amount compared to the disturbance. This active suspension system can be used in various applications such as cars, tractors, or other vehicles.

Review of Previous Work

In 2006, Blake Boe and Tyson Richards worked on a project similar to ours. They successfully built an active suspension system that reduced input disturbance by 75% with a load of 30 [lbf] and by 87.5% without a load. They had developed a proportional control system for the active suspension project. In order to complete the project, the previous group also located parts for the project that matched the design specifications. We selected some different parts to use over the previously selected parts; these different parts are indicated in bold in Table 8.1.

The previous group chose to use a EMAC Micropac 535 as the microcontroller on which to implement their control system. We chose to use an Atmel ATmega128 microcontroller instead since we have much more experience with it and already have some libraries developed. Both microcontrollers meet design specifications in processing power, onboard memory, and digital I/O ports. The previous group also used a 4N25 optical isolator. We chose to use the 6N137 isolator chip instead because it has a low enable current capable of being driven by a microcontroller, and it has a logic-level output to match the logic-level input of the H-bridge. Additionally, the chip has a faster switching speed of 10MBd, a higher isolation voltage of 5300V, and was readily obtained from Professor Gutschlag.

Most of the components we reused were retrofitted into a frame developed by an older active suspension system in the 1990-1991 iteration of the project which used pneumatics instead of a linear actuator. The previous group selected the MSK-4227 H-bridge, IDC EC2-H Electric Cylinder, two P1613 position sensors, a Maxi-Torq 4Z394 motor, and a VPLE-212 camshaft. Although we have yet to test all of the other parts, they have been known to be functional ten years ago. Assuming everything is in working order, we shouldn’t have to find any new parts. The completed Active Suspension System from the 2006 group is shown below in Figure 3.1.

Figure 3.1: Functional Active Suspension System Developed by Tyson Richards and Blake Boe in 2006

Patents

There are over 200 patents related to active suspension systems. Because there are so many patents that include this system, a general design of the active suspension system itself can be legally duplicated. After examining a few individual patents, we have found that they all use actuators, sensors, and some sort of electronic controller. However, each offers some additional innovation. Some of these innovations have included a method of reducing power consumption [3], addition of a user alert system [4], and impact harshness reduction [5].

Subsystem Level Functional Requirements

<u>Modes of Operation</u>

Our project will have an “on” and “off” mode. In the “on” mode, we will control the vertical position of a mass on a platform by comparing the current position with a user-defined set point. As the position of the lower platform changes, the system will respond and the upper platform will maintain a nearly static vertical position. The set point will be entered through a keypad, and the disturbance will be created on the lower platform by a rotating cam shaft. We will measure the vertical displacements of the upper and lower platforms using position sensors, feeding the upper position back into the system as an input and using the lower position to make error calculations. The "off" mode will be triggered by an Em_stop signal. In this mode, the system becomes inactive turning off all power electronics. In order to reset the system, a user must manually power cycle the microcontroller. This ensures the system will not start again accidentally.

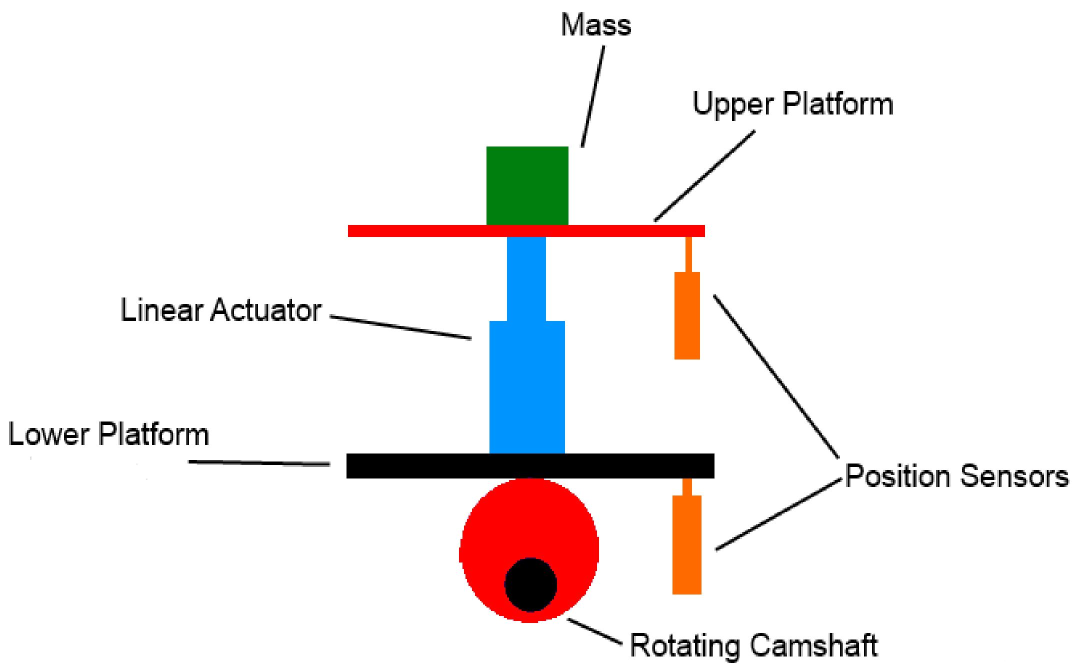

Figure 4.1: Active Suspension System

System Block Diagram

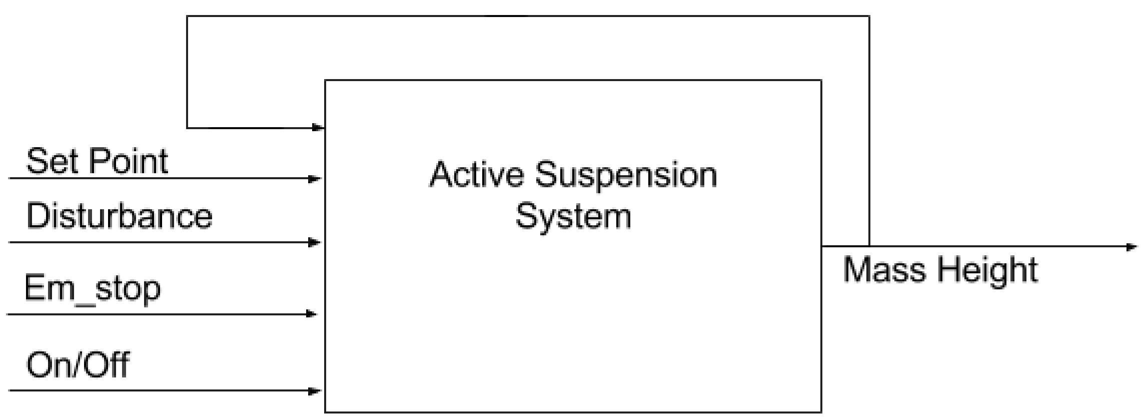

Figure 4.2: Block Diagram of System

Subsystem Block Diagram

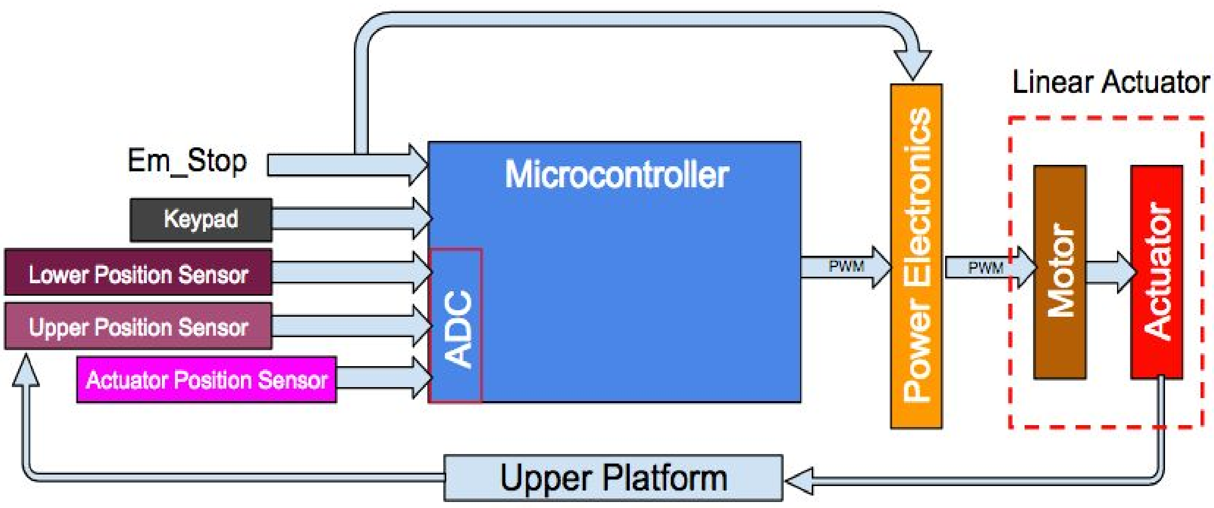

Fig 5.1: Block Diagram of Subsystems

Subsystem Functional Descriptions

Motor and Camshaft

The motor and camshaft are what cause the disturbance in the system. The motor rotates the camshaft, which is essentially an ellipse on a rotating rod. An independently-turning wheel mounted to the lower platform rests on the ellipse. As the rod turns, the wheel is pushed up and down following the curvature of the ellipse on the camshaft. This results in the lower platform being forced up and down in a sinusoidal motion. The objective of our senior project is to minimize the effect of this disturbance on the upper platform.

Keypad

The keypad is connected to the microcontroller and will be used to input the set point, or desired position, of the upper platform. This will be the vertical position that the platform will attempt to regulate.

Lower Position Sensor

This vertically-mounted linear potentiometer is connected to the lower platform and measures the direct disturbance from the camshaft. As the rod of the potentiometer moves up and down, the resistance changes which can be mapped to a vertical displacement. This measurement will allow us to calculate the error from our control system by subtracting this value from the value of the upper position sensor and will be used in tweaking the control system and showing performance statistics in the final document.

Upper Position Sensor

This sensor is connected to the upper platform and measures its position. This sensor will be used to report any and all change in upper platform position. The microcontroller will use this information as feedback to the control system we will be designing to correct the vertical position and calculate the error between the desired and actual platform position.

Actuator Position Sensor

This is the built-in position sensor of the linear actuator. This position sensor will be used to find out how far the actuator is extended and to prevent the actuator from overextending itself.

Linear Actuator

The linear actuator is one of the main components of the system. The linear actuator will extend or retract at high speeds so that the upper platform stays in one place despite any incoming disturbance from the camshaft. The speed and direction of the linear actuator will be controlled with several PWM signals coming from the microcontroller through the power electronics.

Power Electronics

The power electronics are used as an intermediate step between the control signals from the microcontroller and the inputs to the linear actuator. The power electronics block consists of optical isolation chips and an H-bridge. The isolators are used so that voltage spikes on the output side of the chip are completely separated from the input side. In our application, this means that any voltage spikes resulting from rapidly switching the direction of current in the inductor inside the motor do not harm the microcontroller. We will take extra precautions when switching the direction of current in the linear actuator by turning both sides of the H-bridge off and allowing any remaining charge to safely dissipate. The inputs of the H-bridge will be connected to the outputs of the optical isolators and will use the PWM and direction signals generated by the microcontroller to control speed and direction of the linear actuator. With our H-bridge, we can drive a continuous load of 20 Amps at 200 Volts which we wouldn't be allowed to do using only the microcontroller.

Microcontroller

The microcontroller is very important to the system. The key role of the microcontroller is to run a position control system that we will develop. The microcontroller will constantly take the information from the upper position sensor, run it through the control system, and produce output signals that tell the linear actuator what direction to move and at what speed. The Em_stop signal will be controlled through an on-board switch. Figure 7.1 below is a conceptual flowchart to help understand the control system.

Conceptual Code Flowchart

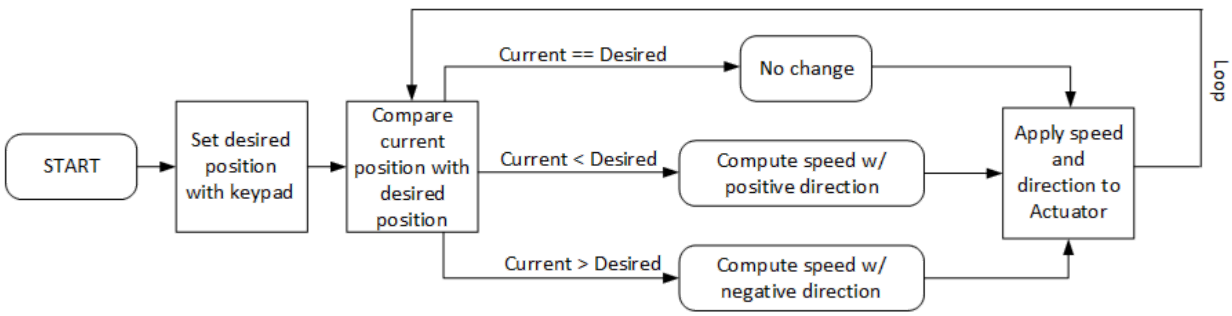

Figure 7.1: Flowchart for Microcontroller Code

The flowchart depicted in Figure 7.1 is merely a high-level overview of what the control system will be doing. It is not an indicator of the actual control system or the resulting code.

Work Completed

<u>Testing the Optical Isolators</u>

During our work this semester, we have accomplished many tasks. The first thing we did was test the optical isolators (see Figure 8.1). Each of the four chips in Figure 8.1 will be connected to one of the logic-level H-bridge inputs. After referencing the datasheet specifications, we set up the isolator chips to use a 620Ω resistor to limit the input diode current. The minimum current needed to drive the LED is 5mA at 5V. Using Ohm's law, we calculated the maximum resistor size needed is 1kΩ. Since we wanted to make sure we were not on the border of turning the LED on or off, we opted to use a smaller resistor of 620Ω. The resulting current using this resistor size is approximately 8mA, which is enough to ensure the diode has been turned on while remaining in spec for the microcontroller's 20mA maximum output current. On the output side, we used a separate LM7805 voltage regulator to power the output side of the chip. Additionally, the output pin of the chip was connected to the open drain of an internal transistor. In order to properly use the chip, the datasheet recommended using a 1kΩ resistor to tie the output to 5V. This value worked for us. After checking the pinout, we then connected the input 5V to a function generator (FG) positive output (sync port), the limiting resistor to the FG's common pin, the isolator's output to the positive end of an oscilloscope probe, and the probe's common pin to the GND pin on the LM7805. We then performed a frequency sweep with the FG and determined that maximum switching speed possible was just under 1MHz, which is plenty more than required for our control system.

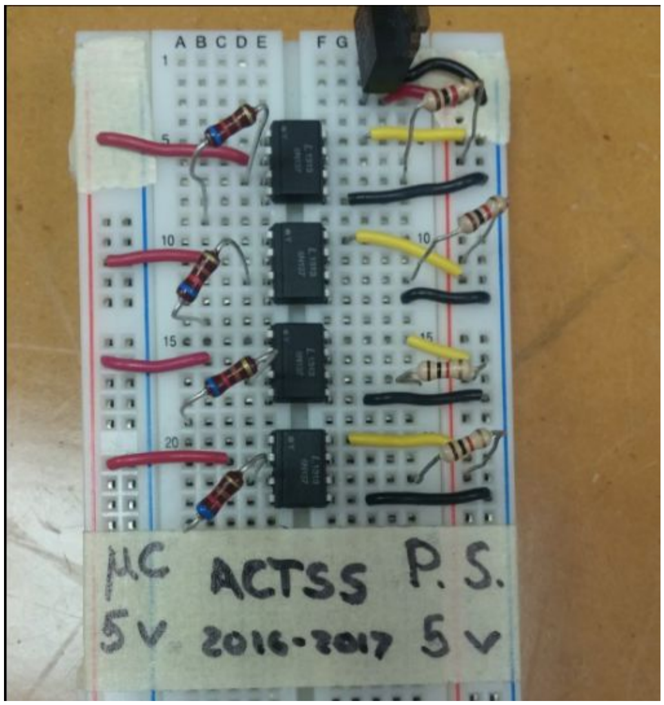

Figure 8.1: Optical Isolator Test Circuit

Testing the H-bridges

Once we had confirmed that the optical isolators were functional, we started to work on the MSK4227 H-bridges. We had 2 different MSK4227's available, so we tested them both to check for functionality. The first one we tested failed. However, the second MSK4227 worked as expected. Before testing the H-bridges, we needed understand how they operate. After a thorough lecture from Professor Gutschlag and further research, we gained a solid understanding of the H-bridge's functionality. A basic H-bridge is made up of four transistors usually consisting of two PNP MOSFETs and two NPN MOSFETs as modeled in Figure 9.1. A load is attached to two center points between the upper and lower gates on each side of the H-bridge, modeled by a resistor in the figure. When HINA and LINB (L) are turned on and LINA (L) and HINB are turned off, current flows from Vdd through HINA to point A0, across RL to B0, and

down through LINB (L) to the chassis ground. In this state, current flows through the load in a positive direction.
Now, we can turn off HINA and LINB (L) and turn on LINA (L) and HINB, allowing current to flow from Vdd down through HINB to B0, through RL to A0, and down through LINA (L) to the chassis ground. In this state, electricity flows across the load in a negative direction. This configuration of MOSFETs allows us to control the direction of the linear actuator by manipulating the four MOSFET gates. If any one of the four gates in an H-bridge are not functional, we will not be able to use the device in our project.

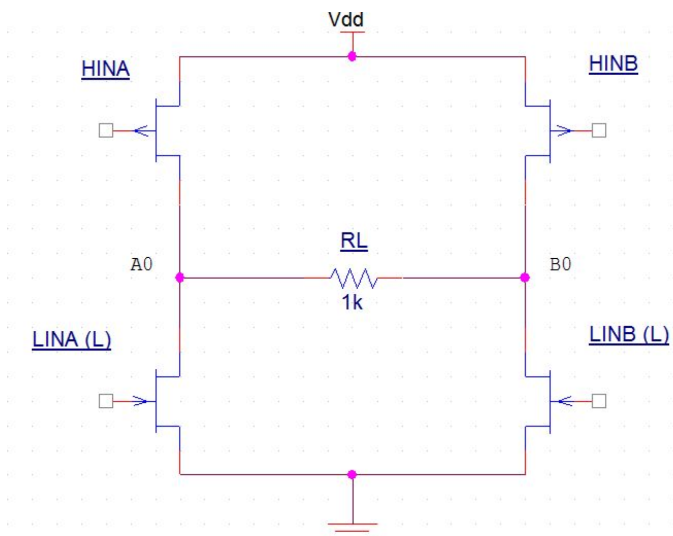

Figure 9.1 H-Bridge Overview

Before we tested the H-bridge, we had to gather some information from the product's datasheet. From the pin descriptions, we learned that we can simply apply Logic-level voltages (0-5V) to the gate driver pins, and internal logic will drive the MOSFETs. Additionally, we learned that HINA and HINB use active-high logic, meaning 5V turns their respective gates on and must be triggered with an oscillating signal no greater than 5.2MHz. LINA (L) and LINB (L) are both active-low inputs, meaning 0V turns the gates on; the pins are tolerant of an applied DC (non-oscillating) input signal.

To test HINA, we connected Vdd to 15V and connected a load resistor of 1kΩ from A0 to the chassis ground. We made sure LINA (L), HINB, and LINB (L) were all open by applying the voltages 5V, 0V, and 5V respectively. Finally, we attached the sync output of a function generator to the HINA gate drive pin, and connected the FG to the common ground. We measured the voltage at A0 using an oscilloscope. To verify the gate worked, we made sure the voltage at A0 was switching in time with the FG output, but made sure we read a 15V signal instead of a 5V signal. Figure 10.1 depicts the scoped signals from A0 pin, the output from an

6N137 isolator chip, and the input signal coming from the FG. From the figure, we can clearly see that all of the signals are synchronized correctly, and the A0 output is showing a 15V signal instead of a 5V signal.

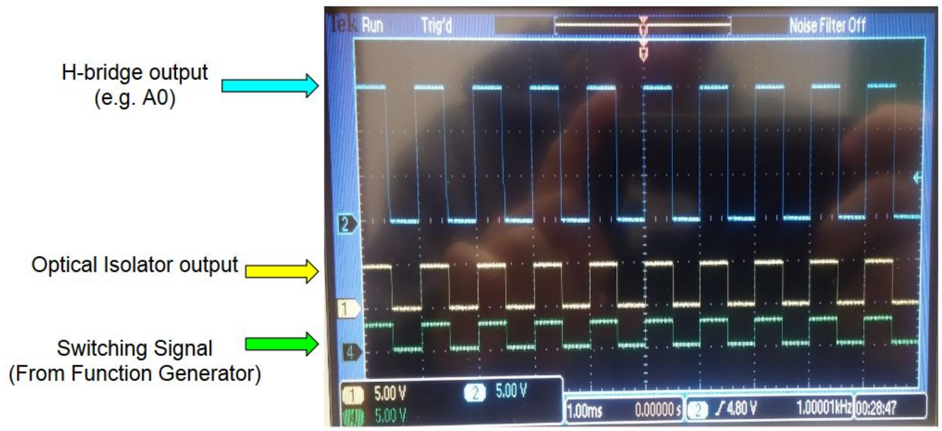

Figure 10.1: Scope Image of Working H-bridge Output

To test HINB, we applied the same steps as above, but connected a 1kΩ resistor from B0 to ground and measured the voltage at B0 instead. To check LINA (L) and LINB (L), we connected the corresponding common points A0 and B0 to Vdd using a 1kΩ resistor, and measured the voltages at A0 and B0 respectively. When testing any single gate, we connected a FG to that single gate pin and verified that all other gates were left open. With this strategy, we were able to test all eight gates on the two H-bridges and accurately determine that one was broken, and the other was working correctly. We are in the process of finding a replacement part if this one should go bad in the future.

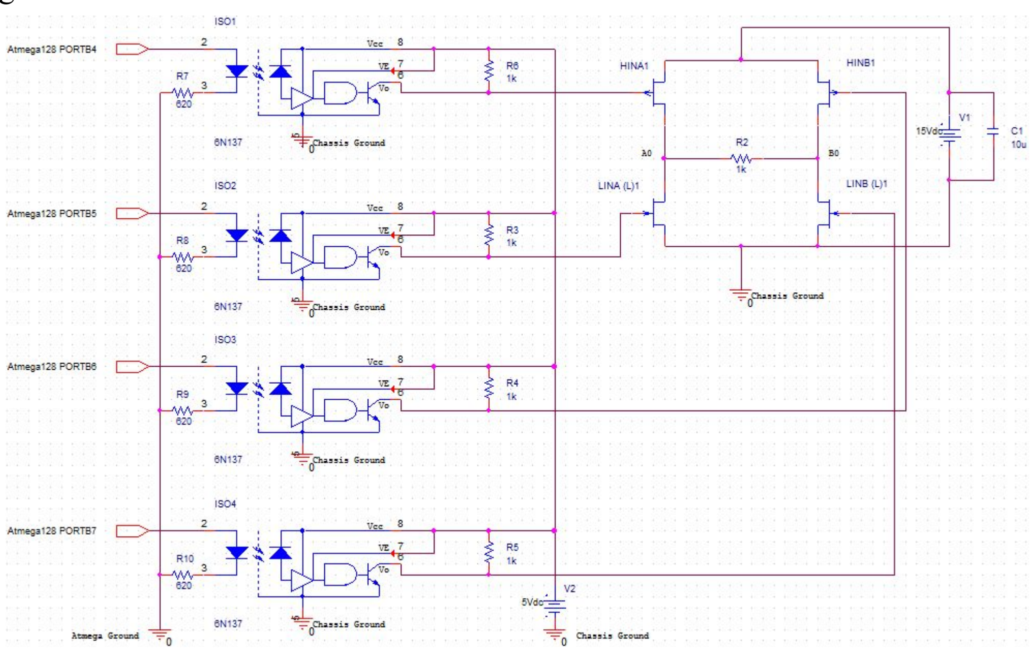

Figure 10.2: H-bridge with Isolation

Parts List

Table 11.1 Parts List

Part	Description	Quantity	Cost ($)	Supplier	Purchased
Atmega128A Dev Kit	**Microcontroller and Development Board**	1	39.99	Waveshare	Y
Keypad	Keypad	1	7.49	Vetco	Y
LCD (HD44780)	LCD Display	1	5.28	Ebay	Y
AVR Dragon	**Atmega128 Programmer**	1	53.75	Mouser	Y
MSK4227	H-Bridge	1	Unavailable	MSK	N
6N137	**Optical Isolator**	4	0.49	Mouser	N
IDC Electric Cylinder EC2H	Linear Actuator	1	540.00	Amazon	N
Maurey Linear Motion Sensor P1613	Position Sensor	2	300.00	Process Industrial Surplus Corp	N
Maxi-Torq 4z394	3-Phase Motor	1	535.00	Amazon	N
VPLE-212	Camshaft	1	83.10	Motion Industries	N
Under Investigation	**Accelerometer**	1	----	Under Investigation	N

Schedule and Division of Labor

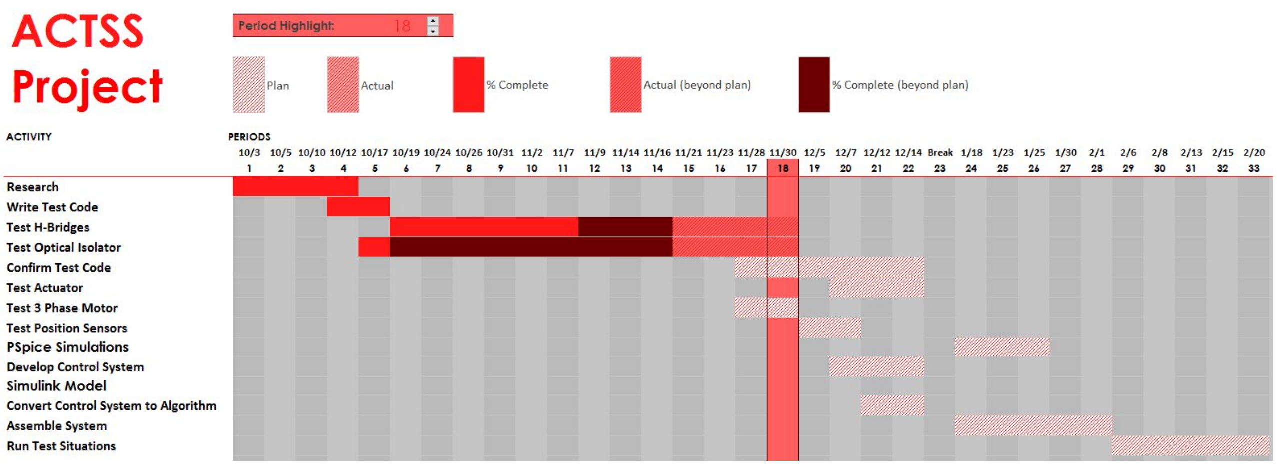

Figure 11.2 Completion Timeline

Table 12.1 Division of Labor

Task	Worked on by	Completed
Research	All	Yes
Write Testing Code	Chase, Xander	Yes
Test Actuator	Rhydon, Josh	No
Test H-Bridge	All	Underway
Test Position Sensors	Josh, Rhydon	No
Test Motor	Rhydon, Josh	No
PSpice Simulations	Rhydon, Josh	No
Develop Control System	Xander, Chase	Underway
Simulink Model	Xander, Chase	No
Convert Control System to a DT algorithm	Chase, Xander	No
Assemble System	All	Underway
Run Test Cases on System	All	No
Documentation	All	Underway
Deliverables	All	Underway

Discussion and Future Direction

We have numerous tasks to complete, as outlined in the Figure 11.2. For research we mainly used the previous senior project documentation and also consulted two main technical papers [1],[2]. We haven't completed a lot of software yet since our focus was testing components from last year, but we have written the test cases of the optical isolators and the H-bridges. As mentioned above, we have thoroughly tested the optical isolators and the H-bridges.

Over break, we will be preparing the next phase of testing and software development. The hardware group, consisting of Josh Rose and Rhydon Vassay, will test the position sensors, the actuator, and the three phase motors. The software group, consisting of Chase Ramseyer and Xander Serrurier, will develop the control system. This will then be coded in embedded C. We also need to make simulations in Simulink and Pspice to verify that our designs are behaving correctly before moving forward with implementation.

References

Previous Senior Projects

Patrice Jackson and Shawn Downey (2003): http://ee.bradley.edu/projects/proj2003/vanchoco/

Blake Boe and Tyson Richards (2006): http://ee.bradley.edu/projects/proj2006/actss/

Research Papers

[1] W.K.N. Anakwa. “Development and Control of a Prototype Pneumatic Active Suspension System.” Bradley University, IL, Oct. 2001.

[2] Q. Zhou. “Research and Simulation on New Active Suspension Control System.” Lehigh University, PA, 2013.

Patents

[3] Giovanardi, et al., “Context Aware Active Suspension Control System,” U.S. Patent 9 440 507, September 13, 2016.

[4] Tarasinski, et al., “Vehicle Active Suspension System,” U.S. Patent 8 065 054, November 22, 2011.

[5] Bradshaw, et al., “Frequency Shaping Method for Minimizing Impact Harshness of Suspension System,” U.S. Patent 6 371 459, June 8, 1993.