BRADLEY University

Department of Electrical and Computer Engineering
Senior Capstone Project
Active Suspension System

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Abstract

This paper describes the implementation of an active suspension system using various control methodologies. The basic active suspension system was constructed in 1990 and modified in 2006 to replace the pneumatic cylinder with a linear actuator as the mechanical position control device. Disturbance inputs are generated on the bottom plate by a camshaft driven by a three phase AC induction motor controlled by a variable-frequency drive (VFD). The electronically controlled linear actuator connected to the upper and lower plates limits the vertical motion of the upper plate so that its position is virtually constant independent of the disturbance input. The linear actuator shaft position is controlled by an Atmel Atmega128A microcontroller via digital control signals applied to an optically-coupled H-bridge that applies appropriate voltages to the linear actuator to extend or retract its output shaft as necessary. The initial control algorithm is a simple bang-bang controller currently in the simulation stage to ensure the system model is accurate. This document also discusses the research completed relative to the implementation of more complex digital control algorithms.

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Introduction

The primary goal of the Active Suspension System Senior Design Team (ASSSDT) will be to design an active system capable of eliminating most of the vertical motion imparted to the supported platform by a disturbance input. The system follows the flow shown in figure 4.1. The ultimate use for such a system is most commonly to reduce the effect of disturbances imparted to a moving vehicle by rough terrain to provide a gentle ride for passengers. For this single actuator response arrangement, the lower platform of the system will provide an oscillating vertical motion and the linear actuator attached to the lower platform will extend or retract as necessary to ensure the upper platform maintains the desired position specified by the user. The linear actuator will be controlled by an optically-coupled H-bridge module connected to an Atmel Atmega128A Microcontroller which permits the control algorithms to be coded using Embedded C.

Subsystem Level Functional Requirements

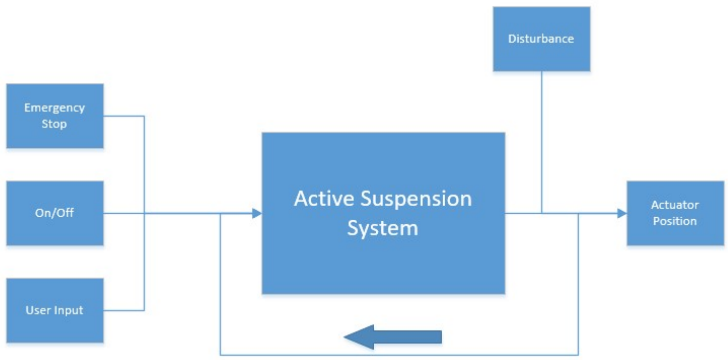

Figure 4.1: System Flow Diagram

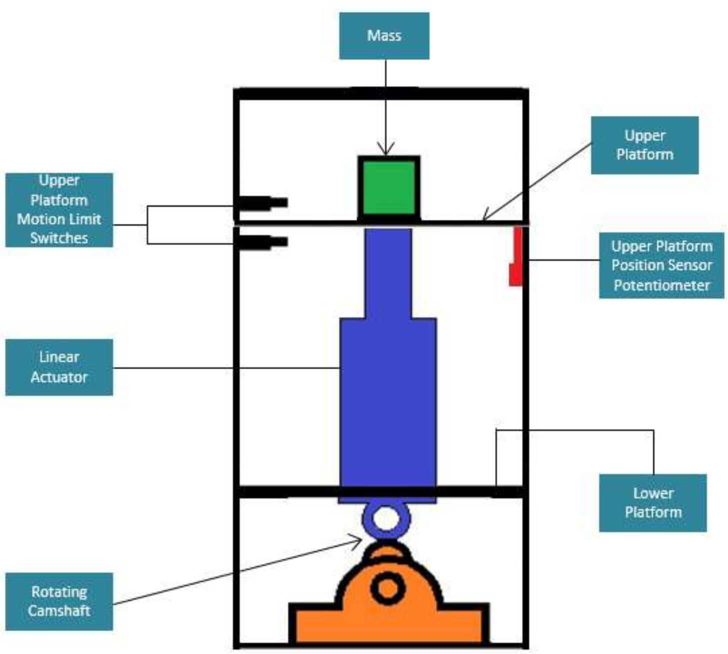

Figure 4.2: Active Suspension System

Subsystem Functional Descriptions

Hardware

Upper and Lower Platform

The system controller implemented with the Atmega128A microcontroller will ensure that the upper platform's vertical motion will be maintained at (or near) the desired position specified by the user. The lower platform will oscillate in the vertical direction and will be controlled by a three-phase AC induction motor connected to a camshaft as shown in figure 4.2. The lower platform oscillation frequency will be controlled by the three-phase AC variable-frequency drive (VFD) used to control the speed of the AC induction motor connected to the camshaft under the lower platform. It should be noted, however, that the camshaft under the lower platform will not provide true sinusoidal vertical motion because the VFD used to control the camshaft speed operates in a "constant torque" mode and not in a "constant speed" mode. Therefore, since the AC induction motor will not drive the camshaft at a constant rotational velocity, the lower platform's vertical motion will approximate sinusoidal motion, but will in fact be slightly distorted.

Potentiometer

There is one potentiometer vertically-mounted onto the system. The potentiometer is connected to the upper platform, as shown in figure 4.2. The potentiometer will be used to measure the instantaneous position of the respective platforms. When a control algorithm is applied to the active system, the lower platform will move a much larger distance than the upper potentiometer during normal operation.

Safety Relays

There are two OMRON MY4N-D2-DC24 4 pole relays utilized to provide for emergency system shut-down as shown in figures 5.1 and 5.2. In the default position, the connection from the Maxi-Torq 4z394 AC induction motor is open, so the cam shaft will not rotate. Once a 24-volt DC signal is applied to pins 13 and 14 in both relays, the relay coil is active the switches will close, disables the brake (which is active low) and connecting the 3-phase source to the AC motor. Two components can switch the relay to its default position once in active mode: the two limit switches and the emergency stop button.

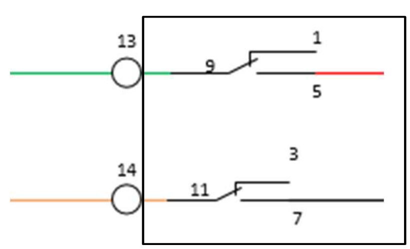

Figure 5.1: Linear Actuator Brake Safety Relay

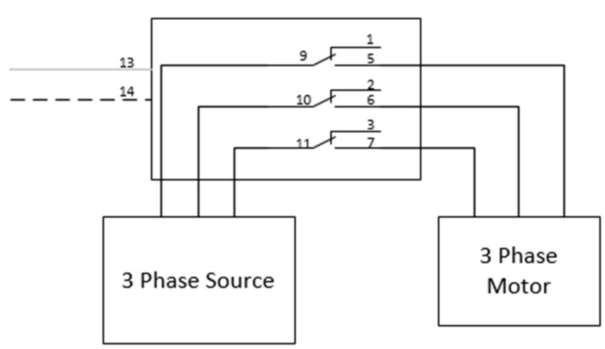

Figure 5.2: 3-Phase Motor Safety Relay

Limit Switches
There are two limit switches connected to the system, as shown in figure 4.2. The switches are included in the system design to guarantee an upper and lower bound of motion in the event of a controller malfunction during development or due to a component failure after the system design is complete. When one of the limit switches is activated, both safety relays will switch to their normally open positions and all system motors will stop (except cooling fans). Note that the linear actuator has an internal brake that will also be activated to lock it in place. However, the AC induction motor is not equipped with a brake, so it will simply settle to its lowest position once it is turned off.

Linear Actuator
The linear actuator will be driven by an optically-coupled H-bridge module connected to an Atmega128 microcontroller used to apply the control algorithms. The actuator is mounted to both the upper and lower platform as shown in figure 4.2. The actuator will extend and retract to compensate for the lower platform movements based on the output of the potentiometer used as the upper position sensor. If the system is operating properly, the upper platform will maintain the position specified by the user input while the rotating camshaft continues to provide disturbances to the lower platform.

Rotating Camshaft
The rotating camshaft will generally rotate at all times during system operation unless the operator turns off the VFD to the three-phase AC induction motor or the emergency stop is activated. The camshaft is located at the bottom of the system, as shown in figure 4.2. The lower platform oscillations are generated by the rotating camshaft driven by the AC induction motor and will simulate the rough terrain alluded to in the introduction.

Basic System Electrical Hardware
The white control box mounted to the top of the active suspension system contains the connections to all subsystems on the apparatus. This includes two LM317 voltage regulators set to provide 12[V] for the cooling fan and 3.3[V], one LM7815 voltage regulator used to provide 15[V], which will act as VCC for the MSK H-bridge, and one LM7805 voltage regulator used to provide 5[V]. There are two OMRON MY2N-D2 safety relays connected to the emergency stop button which can be used to deactivate the linear actuator motor and the AC induction camshaft motor in an emergency. An optically-coupled MSK 4227 H-bridge connected to an Atmega128A microcontroller is used to control the direction and speed of the linear actuator motor as required to maintain the desired upper platform position.

Test Circuit
An additional H-Bridge needs to be constructed for initial software testing purposes to ensure the basic Atmega128A microcontroller software is reliable and fully functional before it is connected to the optically-coupled MSK 4227 H-bridge on the actual active suspension system apparatus. This is considered imperative because the team has only one of the MSK 4227 H-bridges on hand, and a replacement is very expensive. However, if a replacement H-bridge is needed later during project development, two PS21A79 three-phase integrated circuit inverters purchased by the 2016-17 active suspension design team are available.

The additional H-bridge used for code testing will utilize four STP22NS25Z N-channel MOSFETs and four Avago HCPL-3120 optocouplers. The process of designing and troubleshooting the additional H-bridge will also be a very valuable experience because it will help the team better understand the operation of the H-bridge and the software required to effectively control DC motors connected to the system. This is especially true since the MSK 4227 H-bridge on the actual active suspension system apparatus uses bootstrap capacitor high-side drivers which are somewhat difficult to use in practice unless their operational details are thoroughly understood.

Modeling and Control

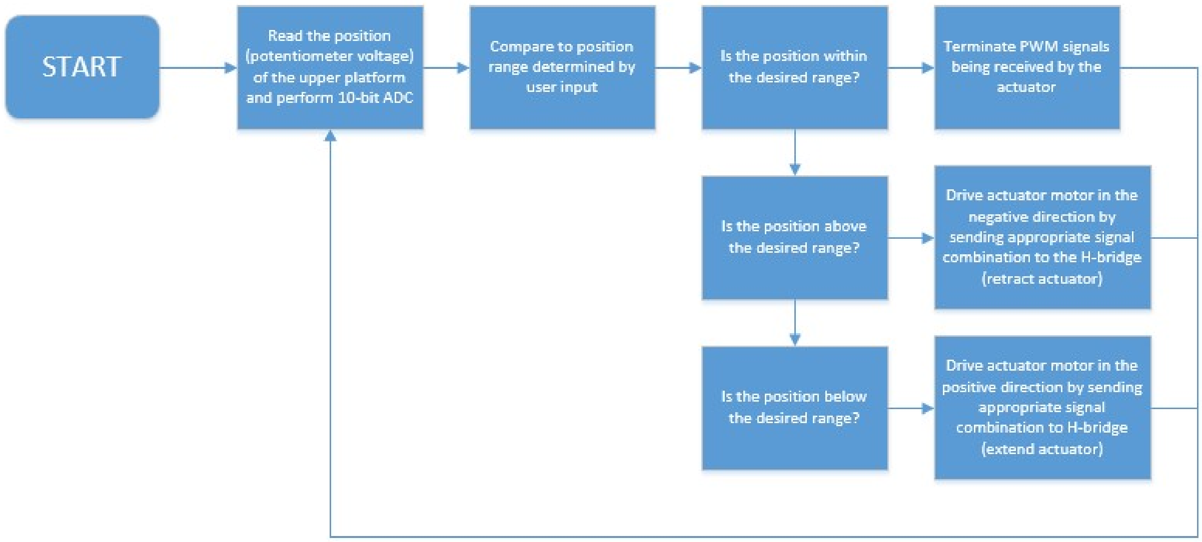

Figure 7.1: Proposed Code Flow Diagram

Atmega128 Board:

The Atmega128A Microcontroller will control the H-Bridge, which in turn will control the direction and speed of the linear actuator. Various controller algorithms will be implemented on the Atmega128A microcontroller board to control platform motion. The bang-bang controller's high-level algorithm is shown in figure 7.1.

Control System

An s-domain model of the linear actuator will be developed in Simulink to simulate operation under various load conditions and input voltages. All of the various control system algorithms will use an Atmega128A PWM signal and the position detected by the upper platform sensor as the feedback control signal. A bang-bang controller algorithm will be implemented initially to verify basic system functionality. Once functional, the team will attempt to design a digital feedback control algorithm to effectively control the position of the upper platform.

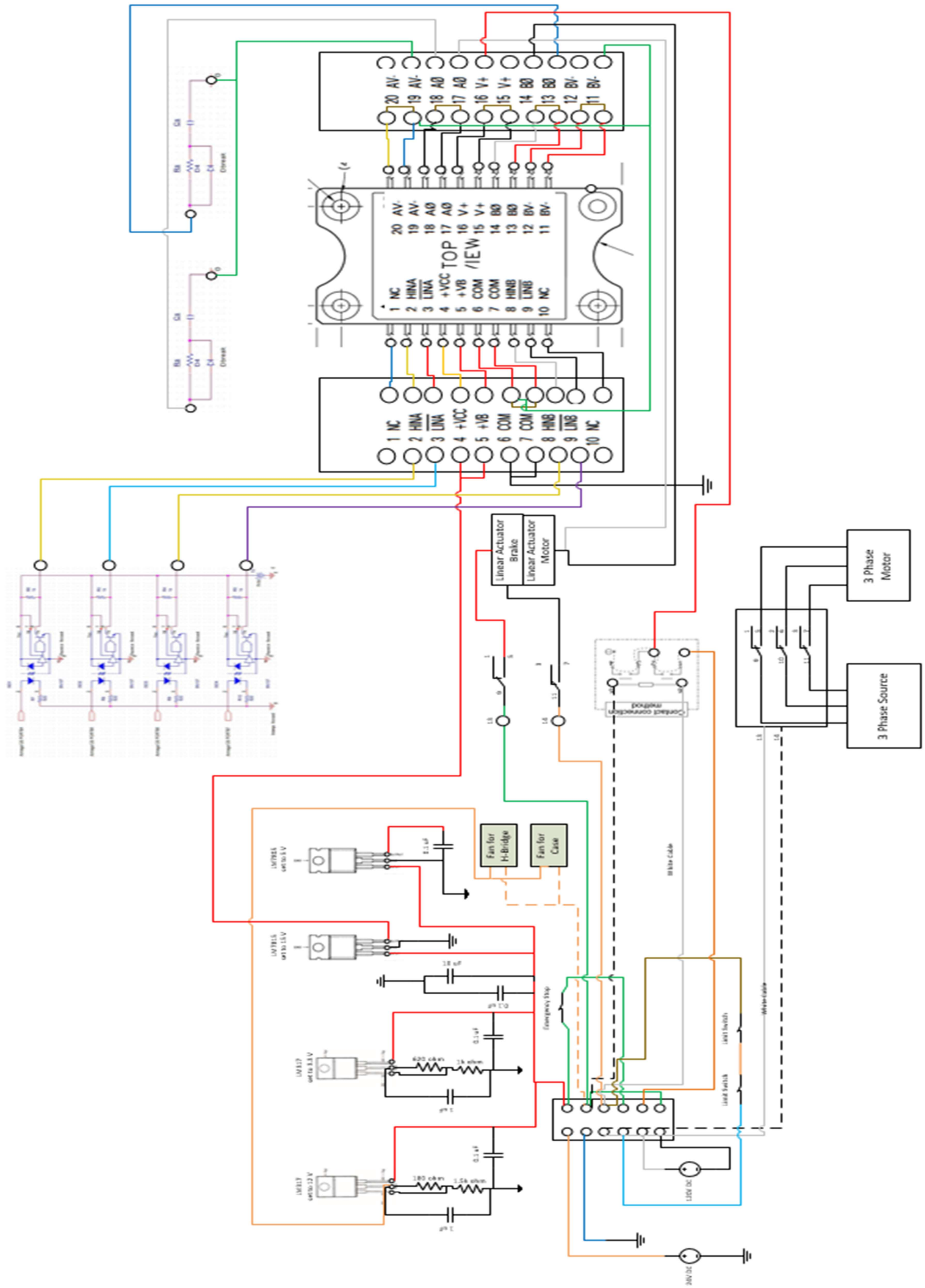

Figure 8.1: Schematic Diagram

Work Completed

Schematic Diagram

Before testing the apparatus, it was already known from the 2016-17 active suspension design team's report that the three-phase AC motor was not functional. In order to diagnose the problem, the team reviewed the previous schematic diagram to diagnose the problem. A more comprehensive schematic diagram was needed, and the team completed the diagram shown in figure 8.1. This diagram was used to verify connections and gain a more complete understanding of the previous modifications made to the system.

Three-Phase Motor

After the system schematic diagram shown in figure 8.1 was generated, the team thoroughly tested the functionality of the active suspension apparatus. The team started troubleshooting the apparatus by first testing the emergency stop switch before applying the three-phase 208 [V] supply to the VFD used to control the three-phase AC motor speed. A 24 [V] DC power supply was connected to the circuit box to test the emergency stop switch for proper operation. As indicated in the system schematic diagram shown in figure 8.1, the emergency stop switch will shut down the entire apparatus and activate the linear actuator brake if the switch is in the closed (depressed) position.

The team used an ohmmeter to test the connection from the source input (pin 9, 10, 11) to the 3-phase motor output (pin 5, 6, 7) with the three-phase 208 [V] supply completely disconnected from the VFD. The team verified that continuity was not present in the normally open position, as there was infinite resistance between the source pins and the output pins. Once the voltage was applied, a resistance was measured which verified connection.

After understanding how the emergency stop switch controls the actuator break and the 3-phase motor, we tested the theory and found that there was no resistance present regardless of the switch being in the open and closed position. As a result of those measurements, the team discovered that the 3-phase AC voltage source was connected incorrectly to the AC motor in the relay. After switching the input connections, the 3-phase motor was functional.

H-Bridge

Since only one MSK 4227 H-bridge is currently available, the design team decided to construct an H-bridge with bootstrap capacitor high-side drivers to gain a better understanding of the basic functionality and to test code before the inputs are applied to the MSK 4227 H-bridge.

As shown in figure 10.1, the discrete component H-bridge consisted of 100[uF] bootstrap capacitors, IN4004PSP diodes, P22NS25Z N-channel MOSFETs, and Avago HCPL-3120 optocouplers. After doing some additional research and listening to Professor Gutschlag's explanation of the H-bridge functionality, the team was able to grasp the fundamentals of the bootstrap capacitor operation relative to the discrete component H-bridge. As shown in figure 10.1, the discrete component H-bridge designed by the team is composed of four N-channel MOSFETs. As a test load, an inductor in series with a resistor was connected between the upper and lower MOSFETs on both sides of the H-bridge. The basic operation of an H-bridge can be described as follows. If inputs HINA and LINB are turned on while inputs HINB and LINA are turned off, the left side of the motor will be connected to the power supply and the right-hand side will be connected to ground. Current will flow through the motor and start the motor rotating in the forward direction. Conversely, if HINB and LINA are turned on and inputs HINA and LINB are turned off, then the motor will be energized but it will rotate in the reverse direction. After the discrete component H-bridge was constructed, the team was able to test its operation with the voltage sources shown in figure 10.1.

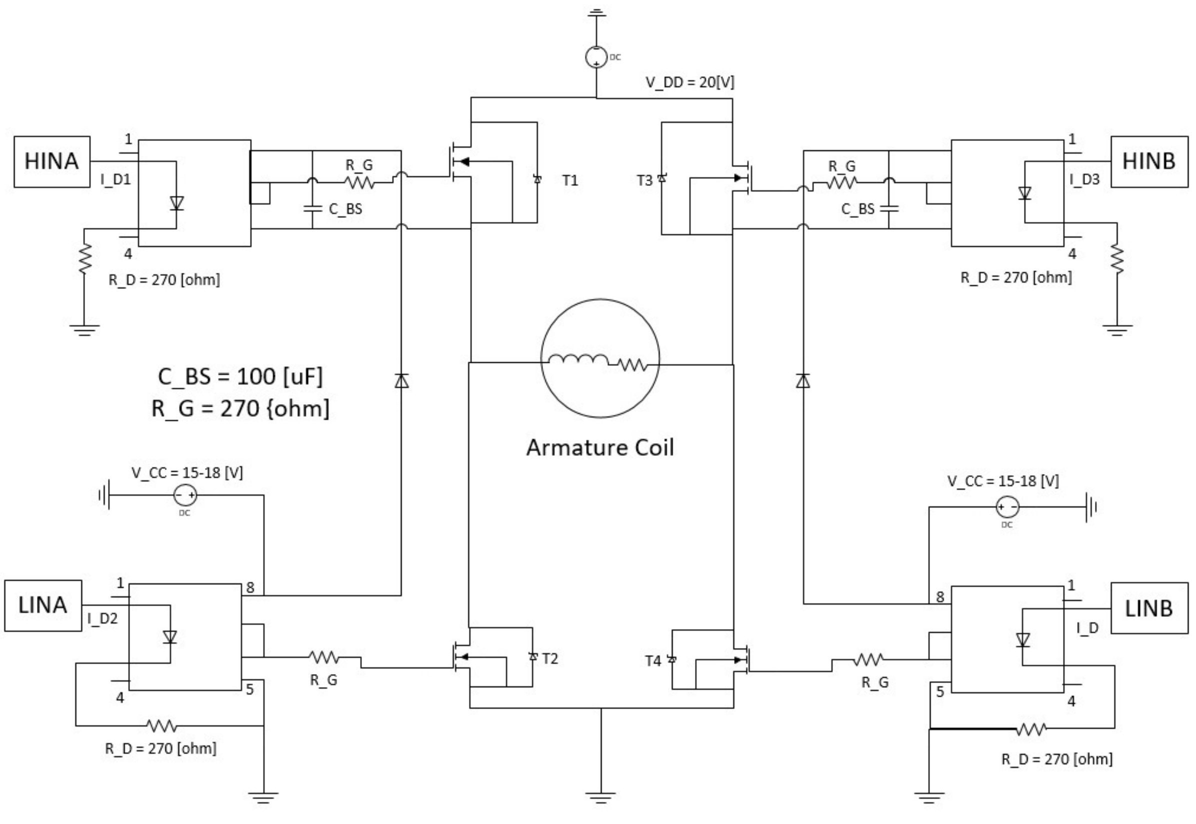

Figure 10.1: H-bridge Schematic Diagram

Future Work

Once the bang-bang controller is functional, a proportional controller will be developed for implementation. Time permitting, a proportional-integrator (PI) controller and a proportional-integrator-derivative (PID) controller will be developed.

Another future goal is to change the feedback component from position to acceleration. An accelerometer was been purchased by the previous team and is currently available.

Schedule

Fall Semester

- 11/08/2018 - 11/28/18: Work on bang-bang control system
- 11/28/18-12/4/18: Finish presentation, website, and proposal

Spring semester

- 1/22/2019 - 3/26/2019: Work on proportional system
- 3/27/2019 - 4/25/2029: If time allows, work on proportional-integral system and proportional-integrator-derivative.
- 4/26/2019 - 5/9/2019: Work on final presentation

Part List

Part	Description	Quantity	Cost [$]	Supplier	Acquired
Atmega128A Dev Kit	Microcontroller and Development Board	1	25.99	Waveshare	Y
Keypad	Keypad	1	7.49	Vetco	Y
LCD (4D44780)	LCD Display	1	~$20-30	Vetco	Y
MSK 4227	H-bridge	1	Discontinued	MSK	Y
IDC Electric Cylinder EC2H	Linear Actuator and Brake	1	~540.00	Amazon	Y
AVR Dragon	Atmega128 Programmer	1	51.61	Mouser	Y
6N137	Optical Isolator	4	1.79	Mouser	Y
Maurey Linear Motion Sensor P1613	Position Sensor	1	299.99	Process Industrial Surplus Corp	Y
Maxi-Torq 4z394	3-Phase Motor	1	543.79	Electric Motor Warehouse	Y
VPLE-212	Camshaft	1	43.67	Amazon	Y
ADXL335	Accelerometer	1	6.62	Digikey	Y
51-256.025	Emergency Stop	1	22.67	Newark	Y
HEV2AN-P-DC24V	Power Relay	1	99.31	Newark	Y
MY4N-D2-DC24	4 Pole Relay	2	20.84	Digikey	Y
NBF-32016	Enclosure	1	22.8	Amazon	Y
LM317	Voltage Regulator	2	0.78	Digikey	Y
7805	Voltage Regulator	1	0.52	Digikey	Y
7815	Voltage Regulator	1	0.5	Digikey	Y
EE80251S2-000U-999	Cooling Fan	1	3.42	Digikey	Y
PS21A79	Replacement H-Bridge	2	73.47	Digikey	Y
Kw11-2	Limit Switch	2	3.95	Amazon	Y

References

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