Tony Abdo

Portfolio

A compilation of my personal and group projects

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Z-stage (Texas Instruments Intern Project)

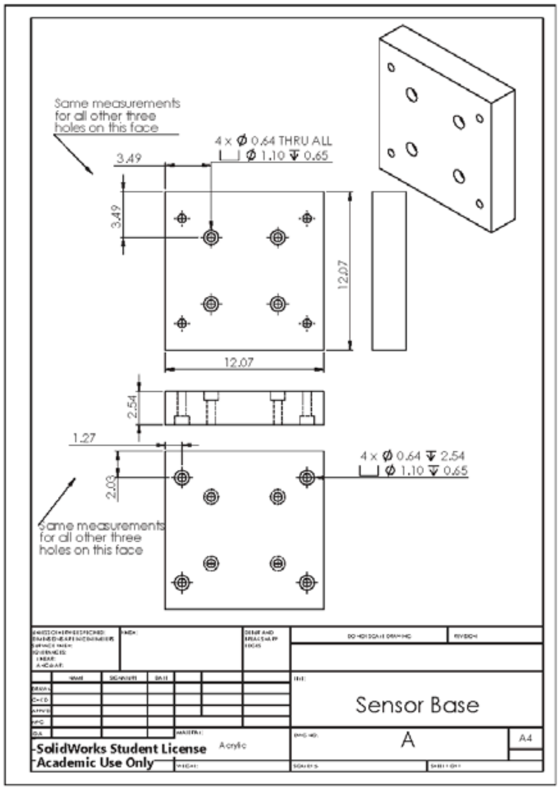
Purpose

At Texas Instruments, the IC's are characterized under different operating conditions and topologies. For the inductive and capacitive sensors, many tests have been carried out that measure the output code as an object approaches the sensor in many different conditions. However, there have been no tests done that characterizes the part while an object slides parallel to it at different distances away since the infrastructure was never there. As a result, my task was to develop a mechanical system that would allow for this type of testing to take place in a repeatable manner.

Tasks Completed

When I started designing the product I made sure that it would be structurally sound, isolate the sensor from any metal interference, make sure it can interface with the actuators that TI already owned, and keep the cost low. First goal was achieved by doing some statics on paper for parts that could potentially cause issue. Second goal was achieved by making part out of acrylic. Third goal was achieved by obtaining models of actuators and using them as reference. The last goal required me to build everything myself using limited amount of tools. Additionally, I wrote code in Teststand and LabVIEW to automate the procedure, collect data from the part, and check for values out of bound. All of this was completed in roughly three to four weeks.

Drawings



Same measurements for all other three holes on this face
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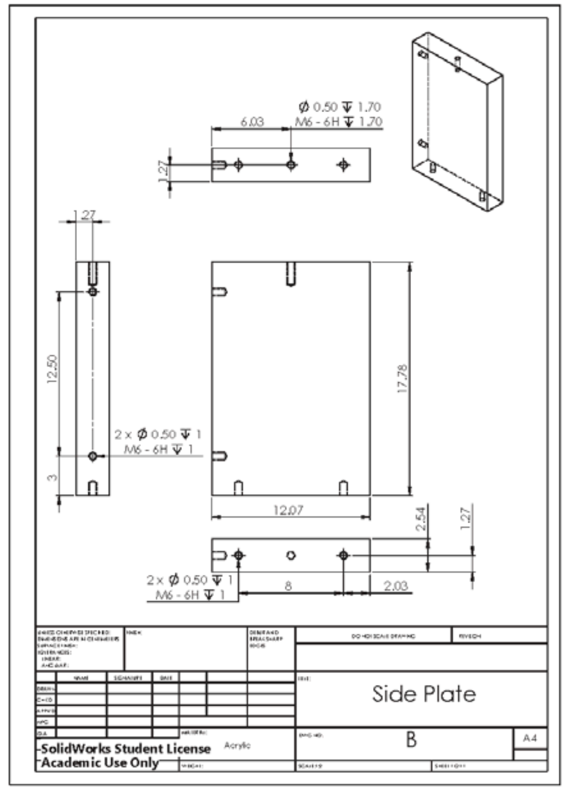
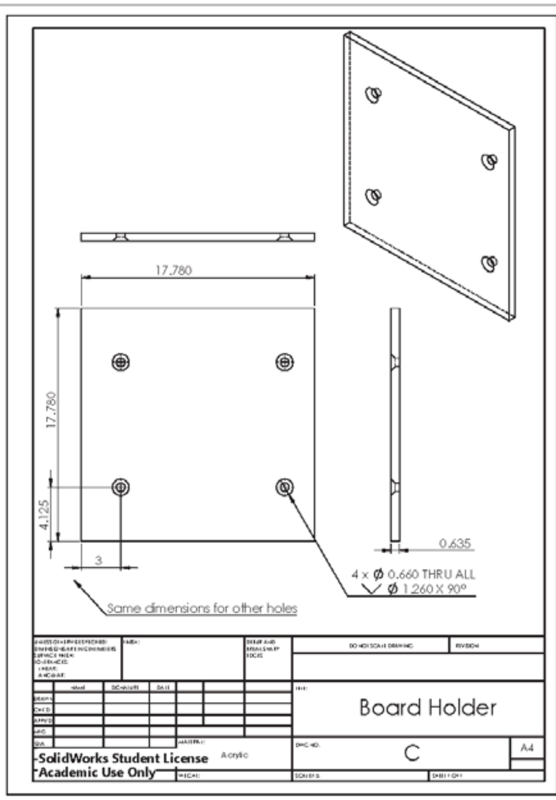
Ø 1.10 ↧ 0.65
3.49
3.49
12.07
12.07
2.54
1.27
2.03
4 x Ø 0.64 ↧ 2.54
Ø 1.10 ↧ 0.65
Same measurements for all other three holes on this face
Sensor Base
A
A4
Acrylic
SolidWorks Student License
Academic Use Only



Ø 0.50 ↧ 1.70
M6 - 6H ↧ 1.70
6.03
1.27
1.27
12.50
3
2 x Ø 0.50 ↧ 1
M6 - 6H ↧ 1
17.78
12.07
2.54
1.27
2 x Ø 0.50 ↧ 1
M6 - 6H ↧ 1
8
2.03
Side Plate
B
A4
Acrylic
SolidWorks Student License
Academic Use Only



17.780
17.780
4.125
3
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Ø 1.260 X 90°
Same dimensions for other holes
Board Holder
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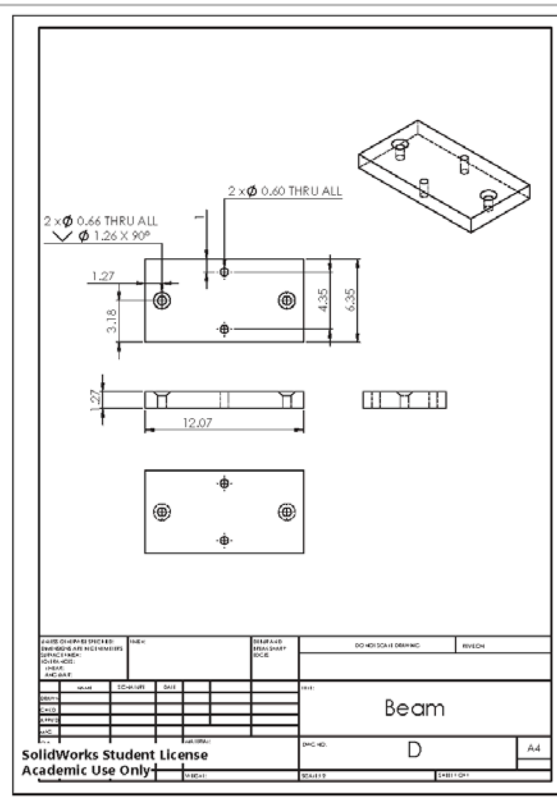
Acrylic
SolidWorks Student License
Academic Use Only



2 x Ø 0.60 THRU ALL
2 x Ø 0.66 THRU ALL
Ø 1.26 X 90°
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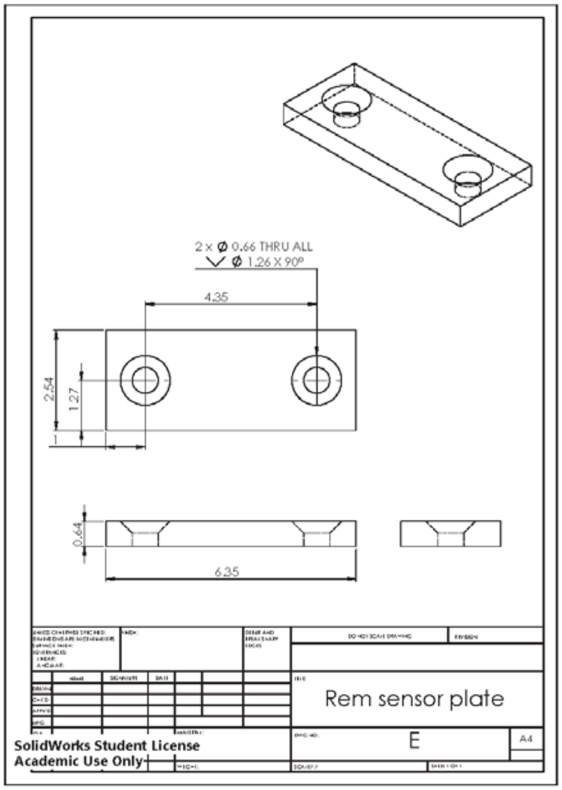
1.27
3.18
4.35
6.35
1.27
12.07
Beam
D
A4
SolidWorks Student License
Academic Use Only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⌵ Ø 1.26 X 90°
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2.54
1.27
1
0.64
6.35
Rem sensor plate
E
A4
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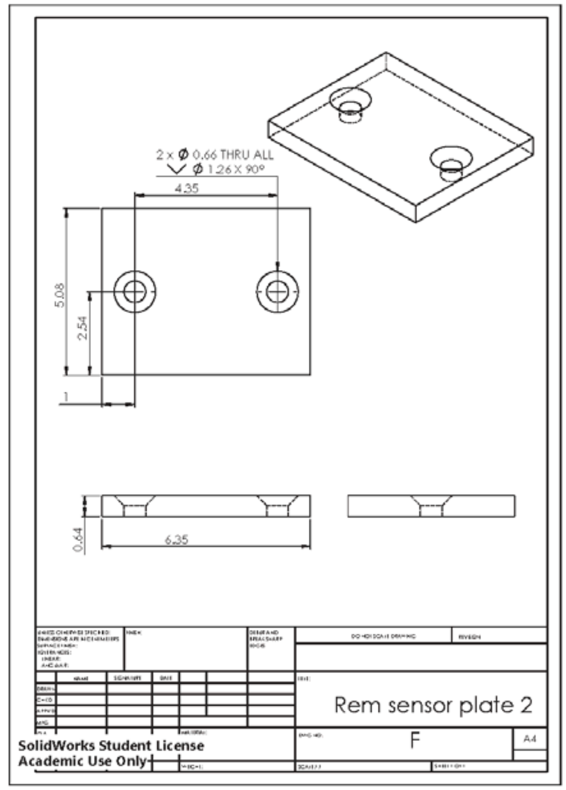
Academic Use Only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⌵ Ø 1.26 X 90°
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5.08
2.54
1
0.64
6.35
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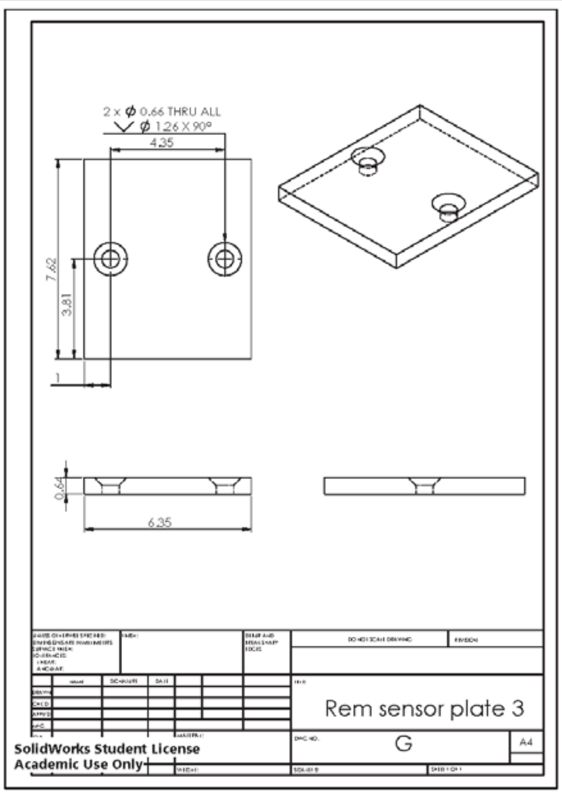
Academic Use Only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⌵ Ø 1.26 X 90°
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7.62
3.81
1
0.64
6.35
Rem sensor plate 3
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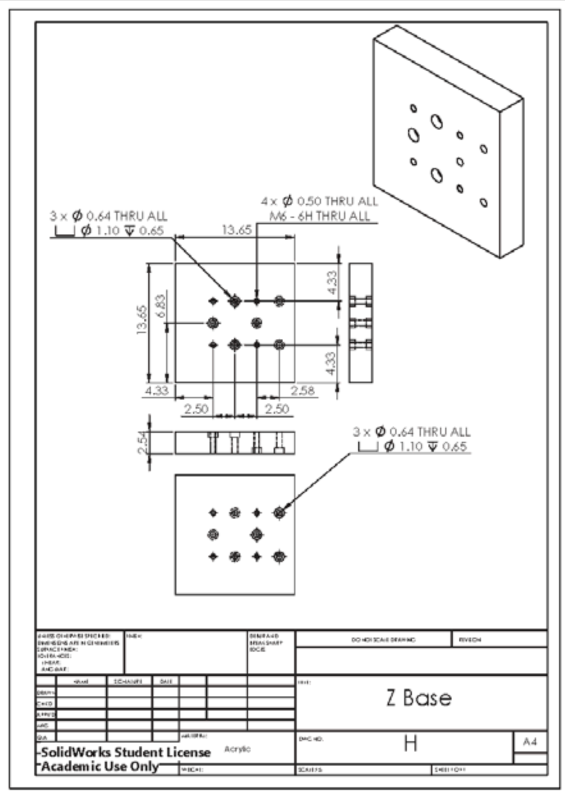
Academic Use Only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⌴ Ø 1.10 ↧ 0.65
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M6 - 6H THRU ALL
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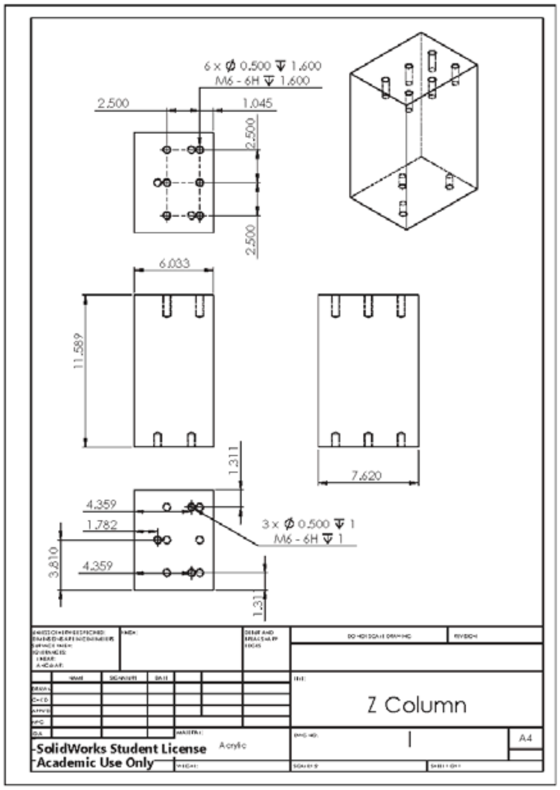
13.65
6.83
4.33
4.33
2.58
2.50
2.50
2.54
3 x Ø 0.64 THRU ALL
⌴ Ø 1.10 ↧ 0.65
Z Base
Acrylic
H
A4
SolidWorks Student License
Academic Use Only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M6 - 6H ↧ 1.600
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1.045
2.500
2.500
6.033
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7.620
1.311
4.359
1.782
3.810
4.359
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M6 - 6H ↧ 1
1.31
Z Column
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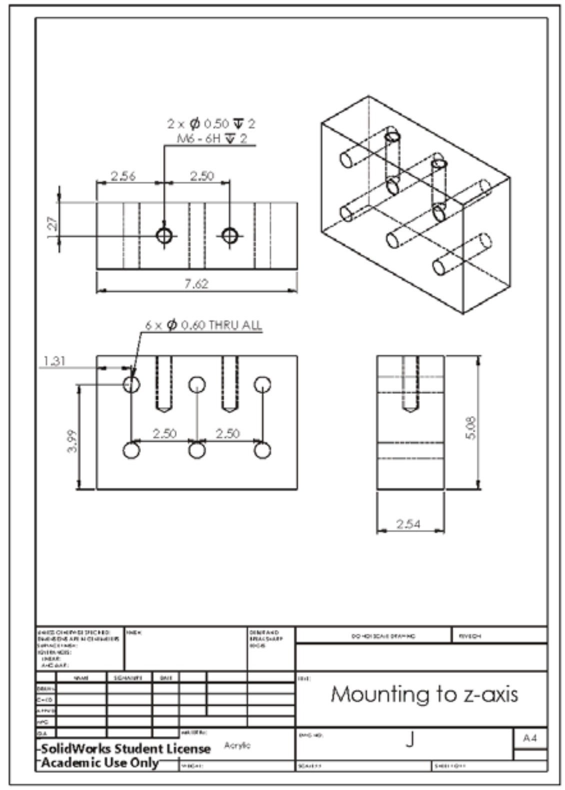
SolidWorks Student License
Academic Use Only
Acrylic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M6 - 6H ↧ 2
2.56
2.50
1.27
7.62
6 x Ø 0.60 THRU ALL
1.31
2.50
2.50
3.99
5.08
2.54
Mounting to z-axis
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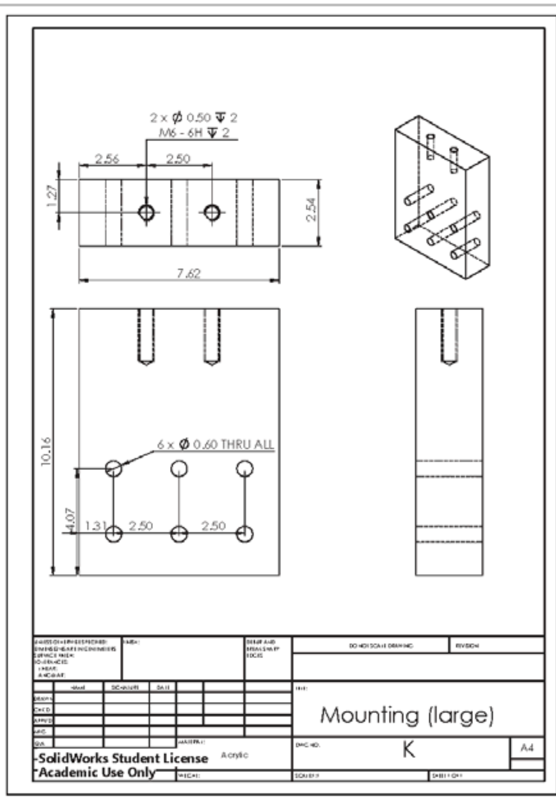
SolidWorks Student License
Academic Use Only
Acrylic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M6 - 6H ↧ 2
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2.50
1.27
2.54
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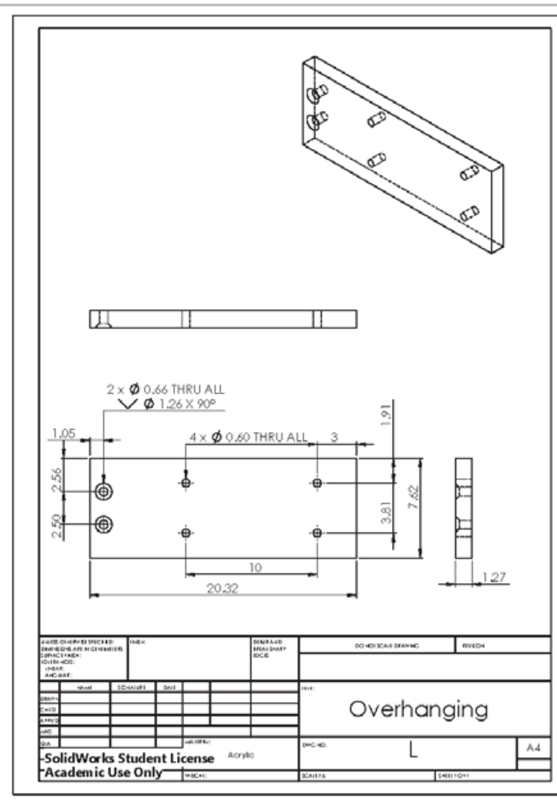
10.16
6 x Ø 0.60 THRU ALL
4.07
1.31
2.50
2.50
Mounting (large)
K
A4
SolidWorks Student License
Academic Use Only
Acrylic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1.05
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1.91
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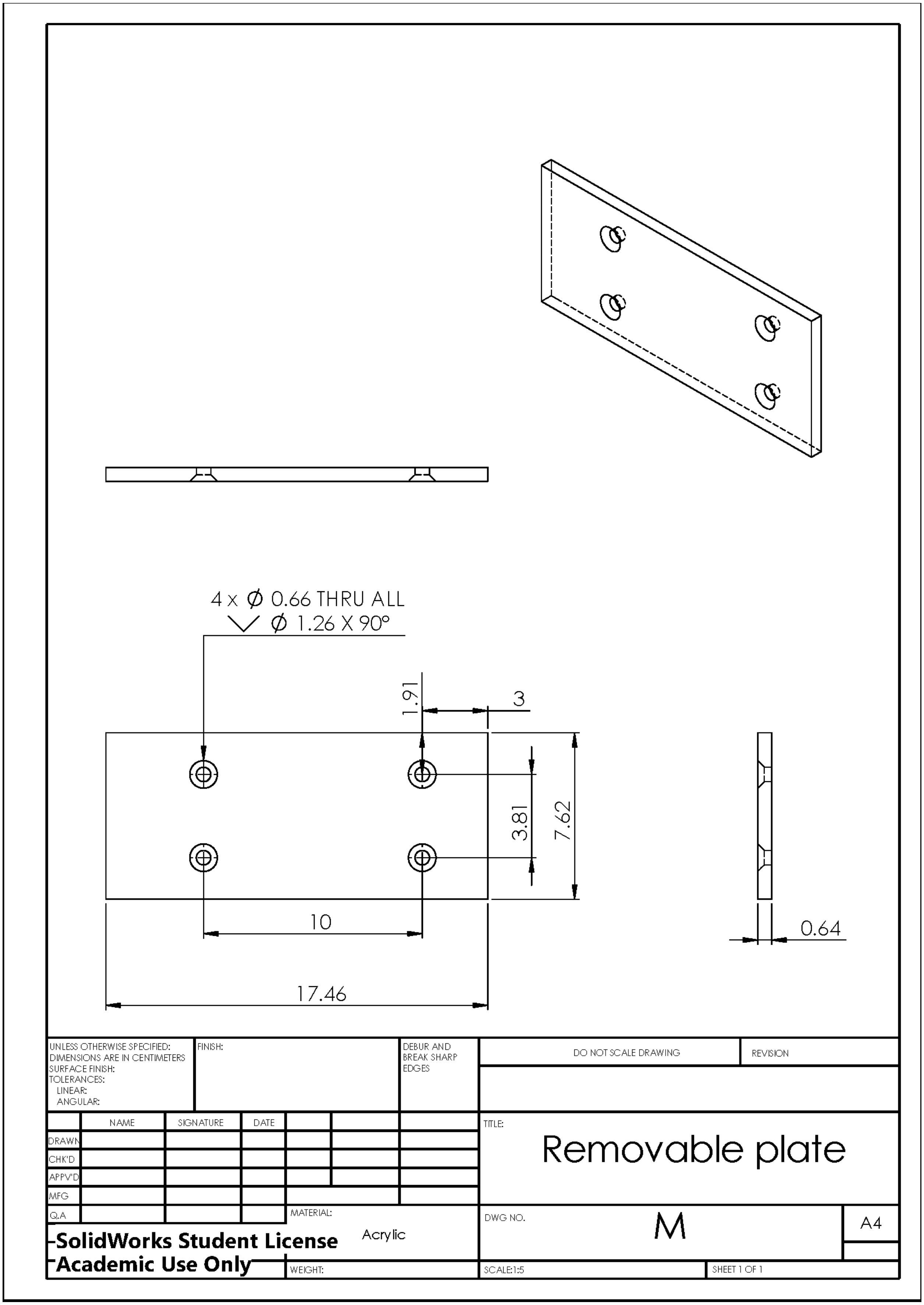
3.81
7.62
10
20.32
1.27
Overhanging
L
A4
SolidWorks Student License
Academic Use Only
Acrylic


4 x Ø 0.66 THRU ALL
Ø 1.26 X 90°
1.91
3
3.81
7.62
10
17.46
0.64
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Removable plate
MATERIAL:
Acrylic
DWG NO.
M
A4
SolidWorks Student License
Academic Use Only
WEIGHT:
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SHEET 1 OF 1

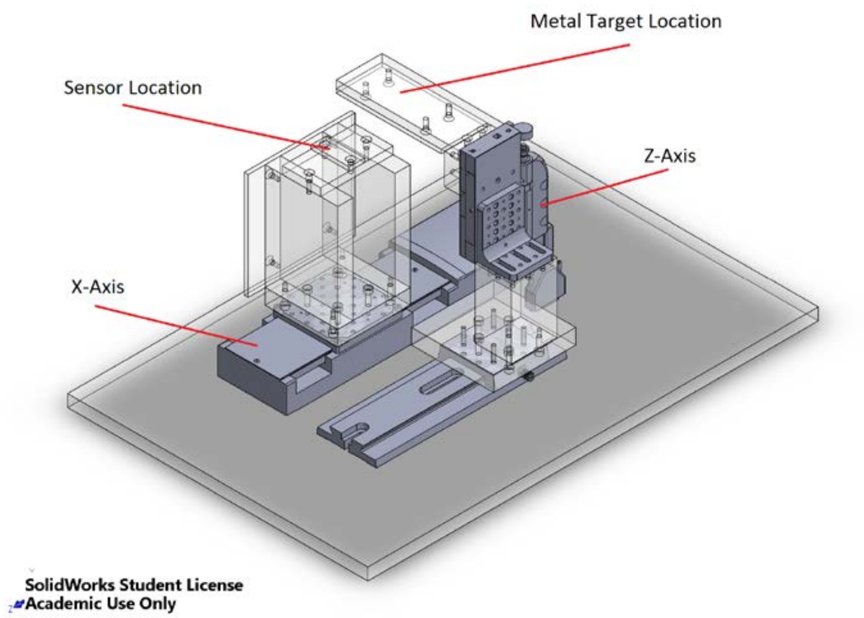


Figure 1: Isometric view of the complete assembly. Items that are clear are designed by me and made out of acrylic, while items in gray were bought already

Final Product

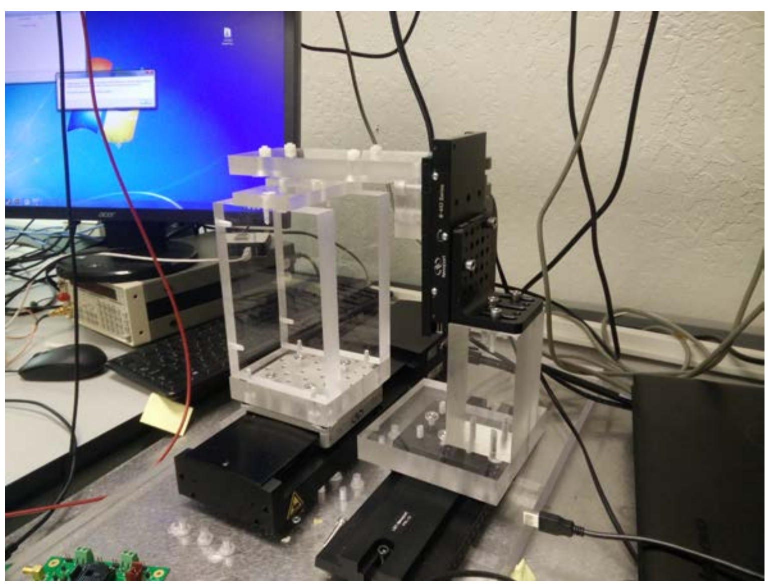


Figure 2: The final assembled product

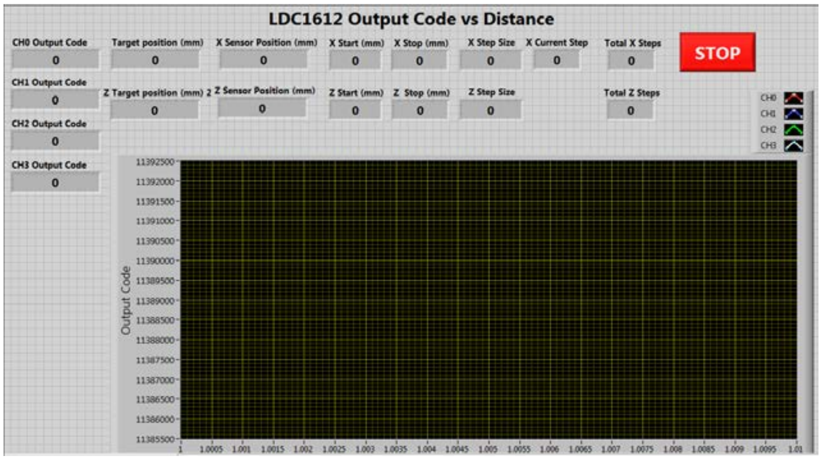


Figure 3: GUI for code written. It displays the code for each interval in the X-Axis and clears the plot when at a new position in the Z-Axis

Back to the Drawing Board (TI DIY Competition)

Description of Competition

This competition was hosted by Texas Instruments and the task was almost completely open-ended. The only requirement was that teams would have to develop either on the Beagle Bone Black or MSP 430.

Goal of the Team

In addition to music, I like other forms of art such as drawing and painting. As a result, I tried thinking of an idea that would help artists improve their trade or at least make it more enjoyable. Artists have recently need to transition in to digital forms such as tablets and drawing pads since many people consume entertainment with their phone. Unfortunately, many artists agree that it does not elicit the same feeling. Thus, I suggested making a mechanism that can allow artists to draw or paint on any surface with any tool, and produce that image digitally as well. The idea that I presented, which got made, was to have two encoders connected to a ring that read off the position of the tool. Since the ring is wide enough, any tool can be placed in it allowing for someone to use this to paint and draw.

My Contribution

When attempting to purchase string potentiometers, we noticed that they were very expensive. As a result, I created a cheap linear potentiometer using an L bracket, badge holder, two spools of thread and a rotary encoder. The mechanism can be seen in *Figure 4*. Additionally, I created the board everything sat on and wrote some code to allow the user to change the color of the pen in the virtual drawing pad.

The Product

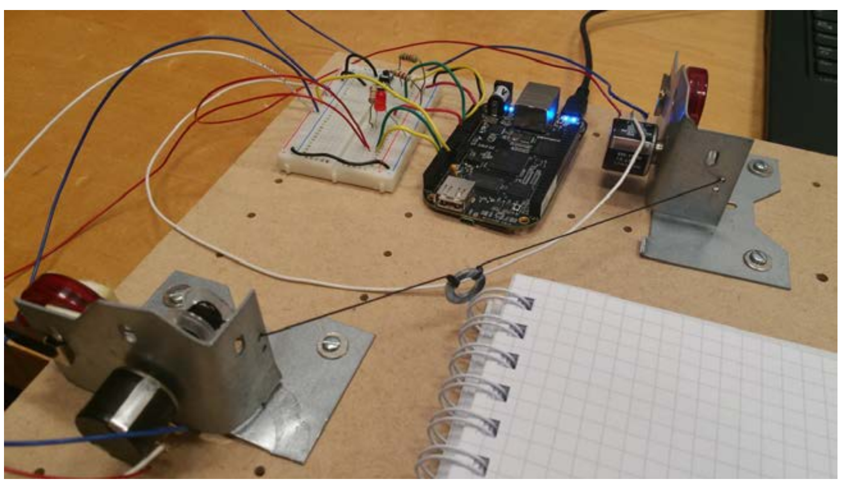


Figure 4: All components of the project

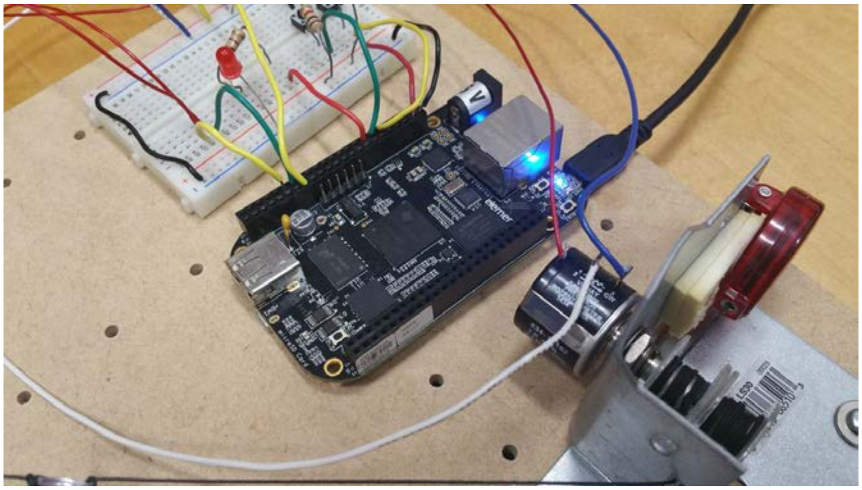


Figure 5: A closeup of the board and the in-house linear potentiometers

A video of this in action can be seen at: https://www.youtube.com/watch?v=Adoah9AO_zU

A more detailed description of project can be found at: https://www.hackster.io/cainstruments/back-to-the-drawing-board

Inverted Pendulum (EE 128/ME 134)

Description of Project

Over the course of a few labs, a variety of control techniques were applied to the problem of making a pendulum balance in an inverted direction which is an unstable equilibrium point. A cart travels along a metal bar using a gear to rail interface, and attached to this cart is a metal beam which is free to spin. In this controls problem, one needs to move the cart to counteract the falling of the beam by moving the cart to "catch" it.

Control Strategy

In order to bring the pendulum up from the stable equilibrium point of hanging down, a bang-bang controller was used which utilizes the idea of conservation of energy to convert the kinetic energy of the pendulum and cart to potential energy of the beam. Once the bang-bang controller gets close enough to the top, an LQR controller takes over and fully stabilizes the system. Additionally, to make the controller as smooth as possible, an observer was used to estimate the velocity of the cart and beam since numerical differentiation can lead to high noise. The controller was implemented using Simulink with the following diagram:

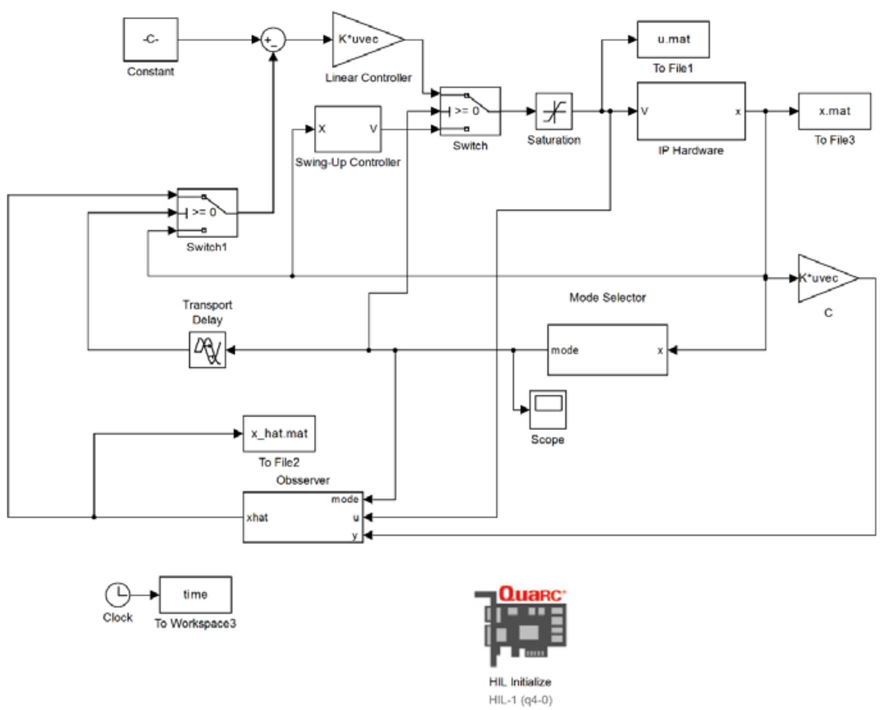


Figure 6: Controller used for Inverted Pendulum problem

:

Results

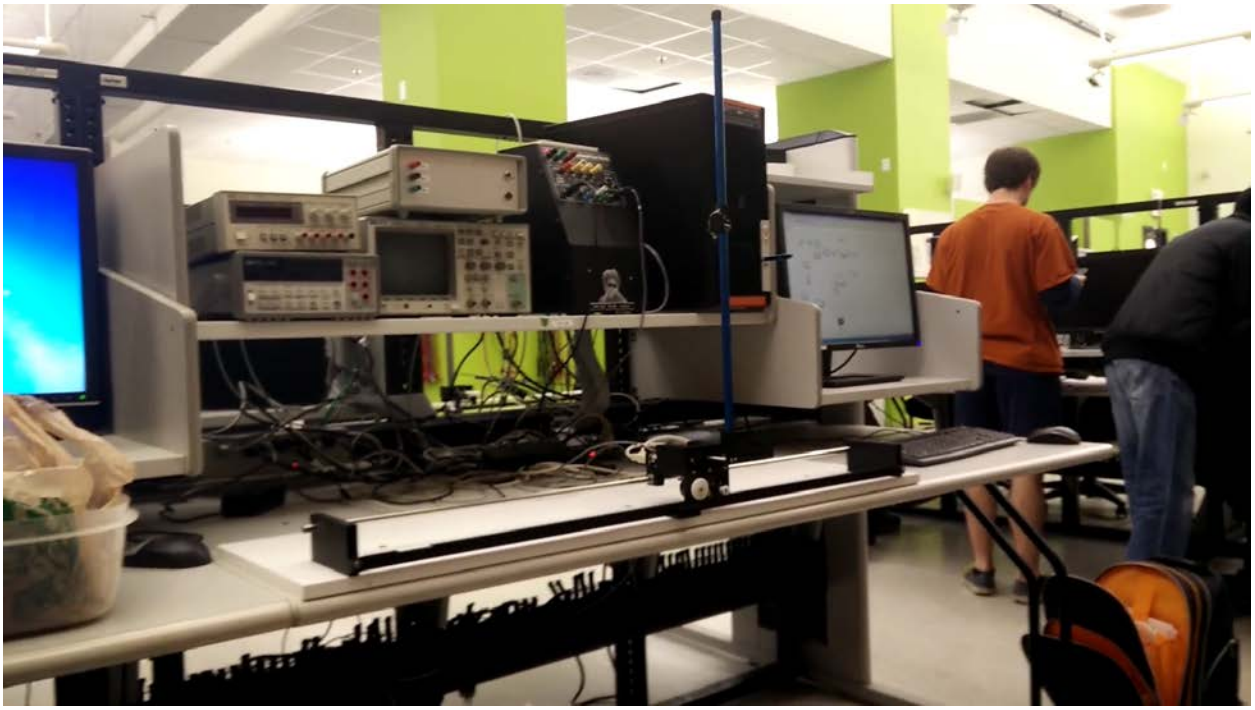


Figure 7: The controller balancing a pendulum with an extra mass at the center of the beam

A video of the controller flipping the pendulum from a stable state and the balancing it while staying as close to start position of the cart with response to perturbations: https://www.youtube.com/watch?v=fFs3c1zJ_dE

A video the controller doing the same thing as previous video except now respond to a sinusoidal reference with respect to the starting position of cart: https://www.youtube.com/watch?v=1288B9Yuy6g

Magnetic Levitation (EE 128/ME 134)

Project Description

The purpose of the project was to levitate a steel ball which required the linearization of the nonlinear dynamics of the system about an operating point and develop a control strategy to make it work. This was done in a lab setting, so all of the equipment was given to us. Our task was to design the controller that would get it to work.

Control Strategy

The controller was implemented using an op amp in negative feedback as depicted in *Figure 8*. The values for R1, R2 and C were chosen such that this became a lead compensator and increased the phase margin of the system. It also made the system stable by pulling the poles into the open left half plane when the loop was closed. Once the ideal controller was designed and the values for the components were found, real-life components were chosen to closely match them. The controller was checked again to see how much the adjusted values affected the performance of the controller by comparing the open loop bode of each topology, and the graph is shown below in *Figure 9*.

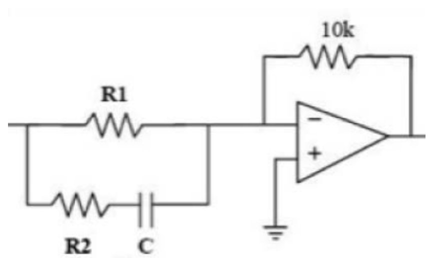


Figure 8: Analog controller used to levitate the ball.

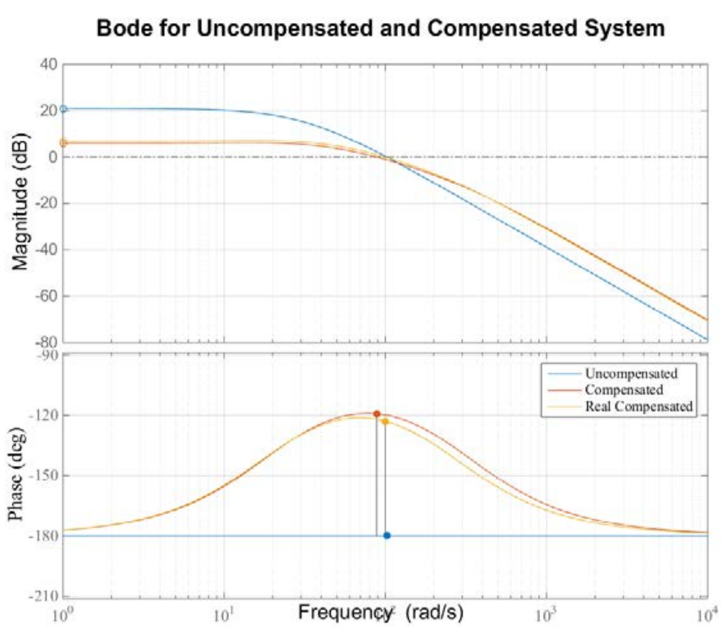


Figure 9: Bode plot of open loop system when uncompensated, ideally compensated, compensated with realistically sized components

Results

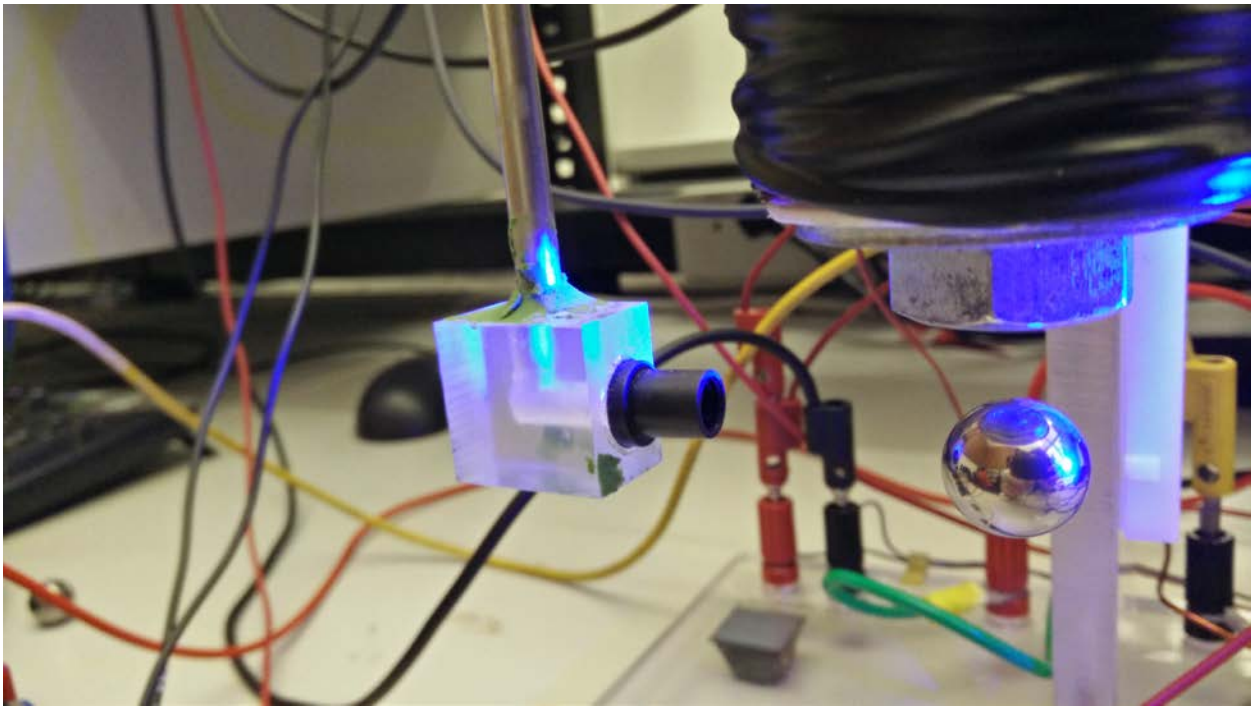


Figure 10: Steel ball being levitated

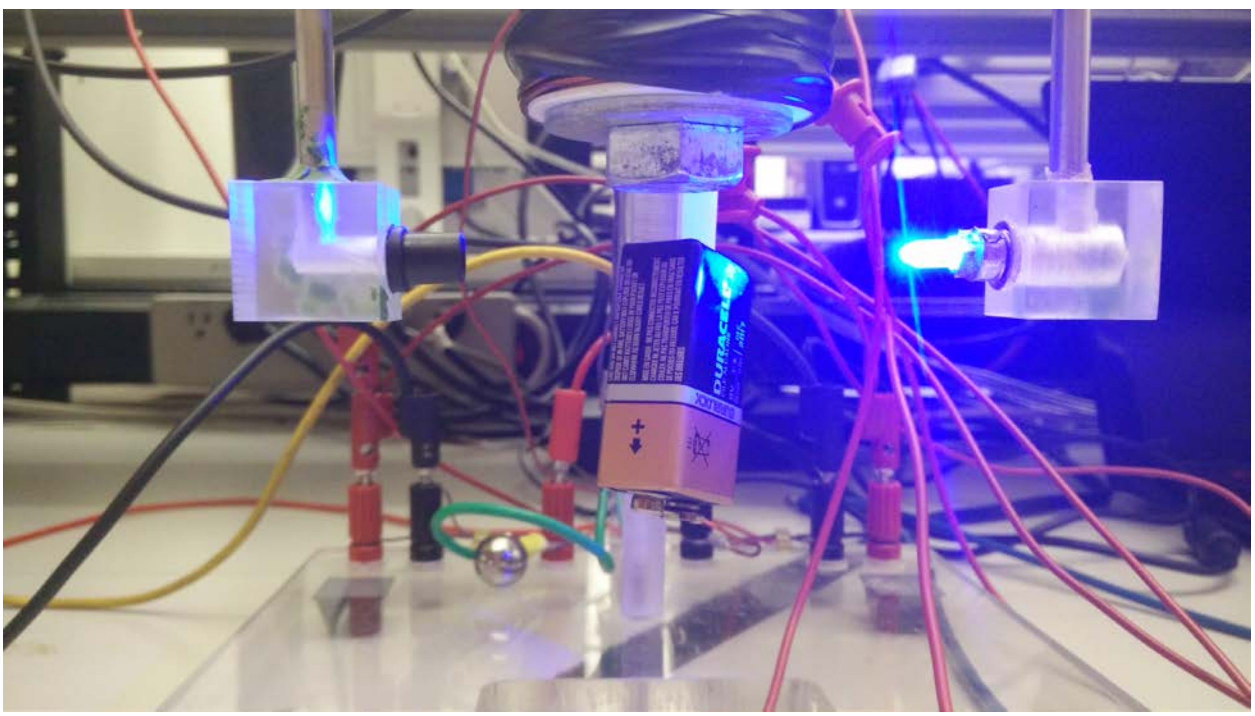


Figure 11: Battery being used with the same control system showing how system is robust to variances in plant

Video of this in action with demonstration of disturbance rejection:
https://www.youtube.com/watch?v=bMzEAnzfDjM

Mini Robot (EE 40)

Purpose of Project

For my introductory circuits class, we built a small robot to learn about various topics such as filter, motor drivers, and op amps. Additionally, we use an MSP 430 to add some logic to the robot.

Circuit Diagram

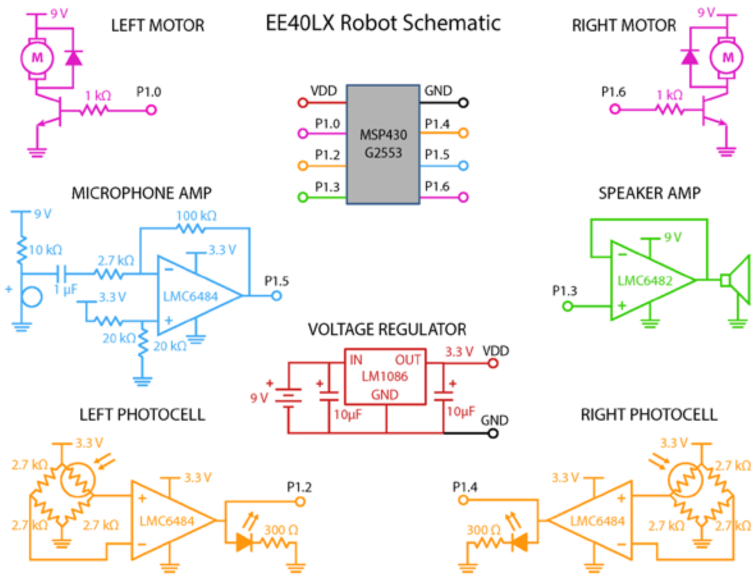


Figure 12: Schematic of all the parts put into the robot

Final Product

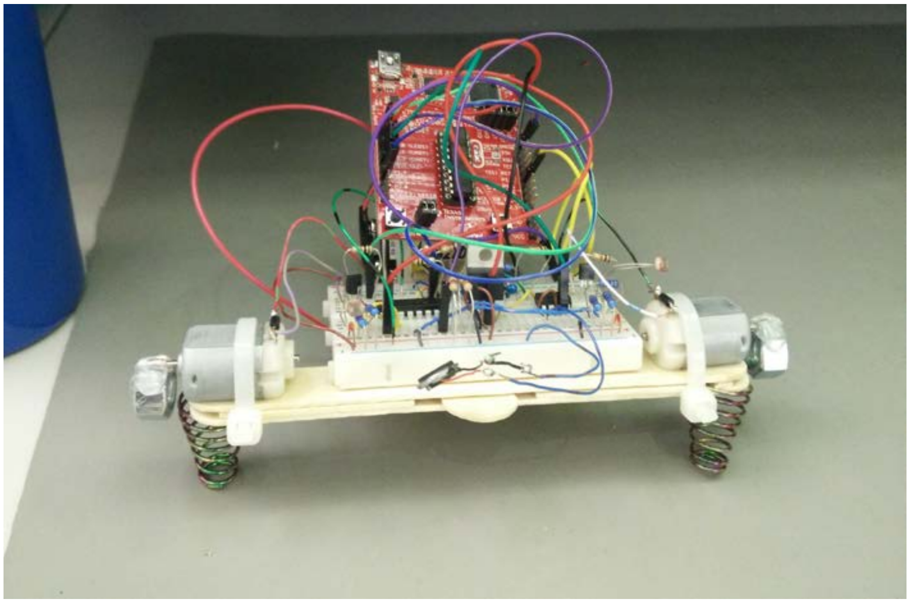


Figure 13: The final robot produced

Dancing Lights (Add-on to Mini Robot)

Purpose of Project

The purpose of this project was to add an extra analog system to the Robot mentioned in the previous section. The limitations were very minimal, so the project was very open ended. Since I was unsure of what to do, I turned to one of my passions, music, for inspiration. After giving the project some thought, I decided to make a circuit that would take any sound through a microphone and filter it with a bandpass filter. The amplitude of this signal would then correspond to the number of LEDs that are lit. I later found out that mechanisms such as this exist and are called vu meters.

A tutorial on building this can be found at http://tonyabdo.com/projects/dancing-lights/

Schematic Design

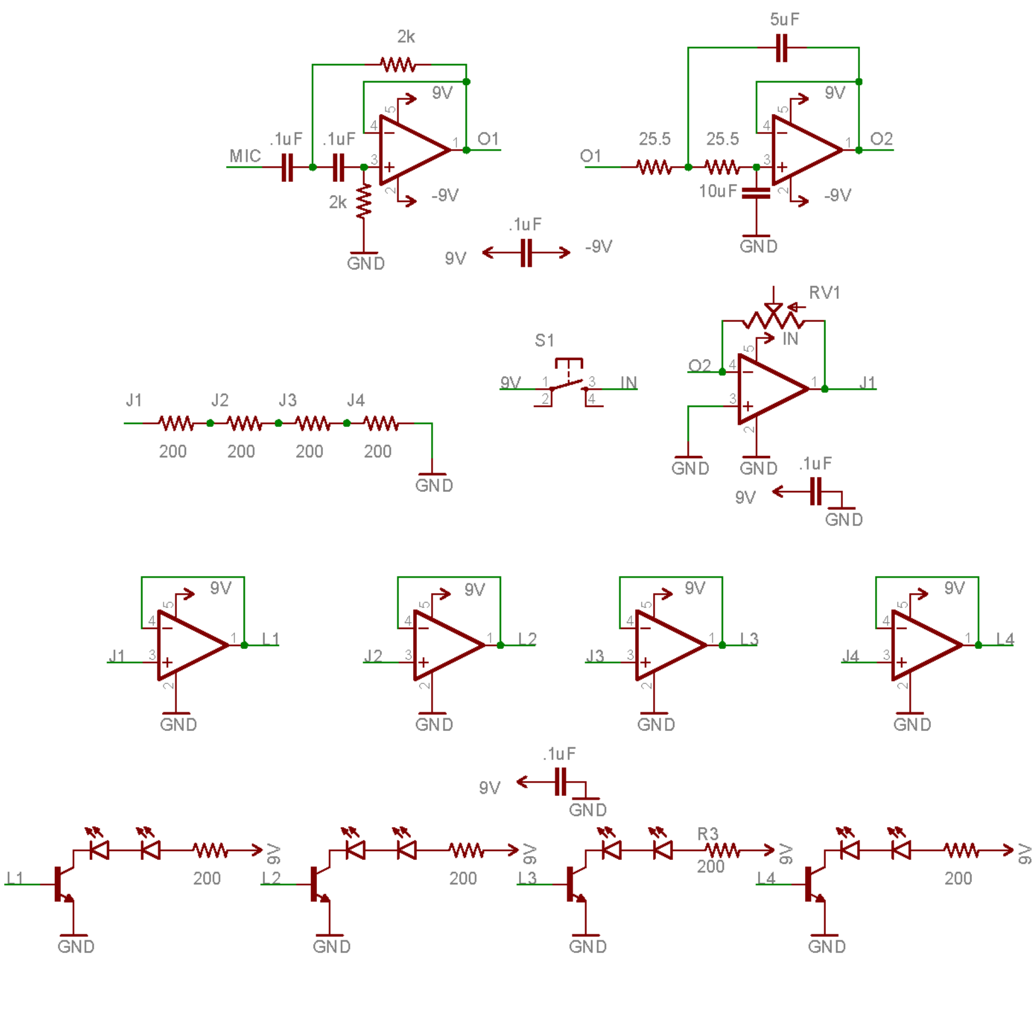


Figure 14: Schematic representation of the circuit I designed

Final Product

Figure 15: All the lights are turned on when the amplitude of the noise saturates the voltage seen across the series of resistors

A video of this circuit respond to the song "Light Pollution" by Lifeformed:
https://www.youtube.com/watch?v=awmV00ETr7M

Rubens' Tube

Project Description

The Rubens' tube is a classic physics experiment used to demonstrate how sound travels as a wave, similar to light. The device works in the following way: a hollow cylinder is sealed off on both ends where one end houses a speaker and the other end feeds propane gas. Then, a series of equally spaced holes are drilled in one straight line on the outside allowing the gas to escape. This escaping gas is lit producing a series of columns of fire. Once a pure frequency is passed through the tube, points of compression and decompression cause more and less gas to escape from the drilled holes, respectively creating a sinusoidal pattern. This is depicted in *Figure 17* in the **Final Product** section.

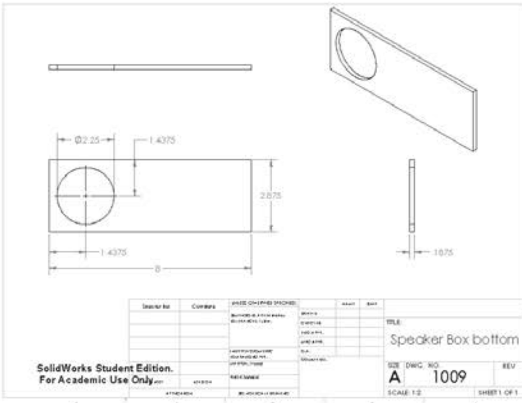
Reason for the Project

Back home, the winter season makes it too cold to sit outside during the night and relax with family. As a result, I thought I should build a heater. However, an ordinary heater is too boring; instead, I wanted something that would also be entertaining. Then, I realized that the Rubens' tube would be the perfect product for the job. Additionally, I thought my brother would benefit from learning a little about how sound works.

Challenges

Most of the challenges came about from the manufacturing process. I did not have the right tools or materials for the job. As a result, I spent a lot of time figuring out where to buy the equipment I needed, and adjust my design accordingly if I couldn't find what I needed.

Drawings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Speaker Box bottom
A
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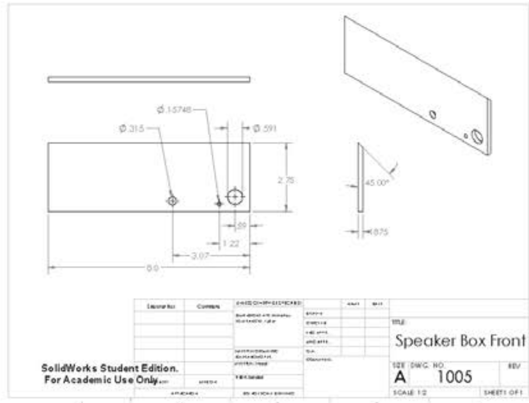
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Speaker Box Front
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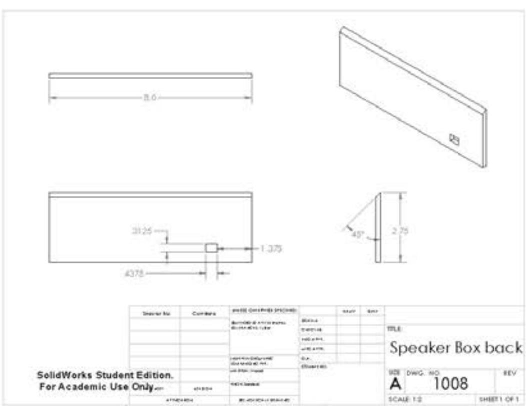
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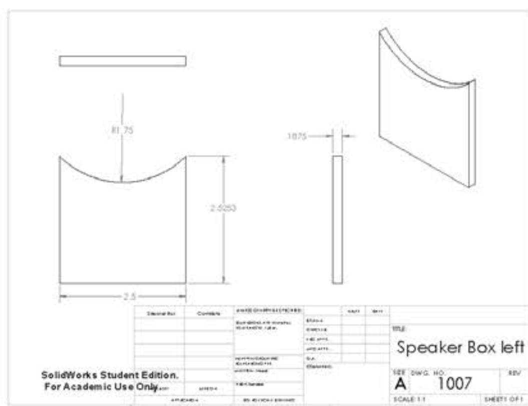
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A
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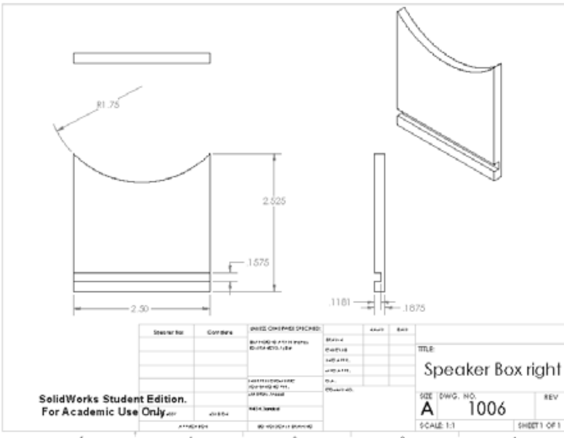
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2.50
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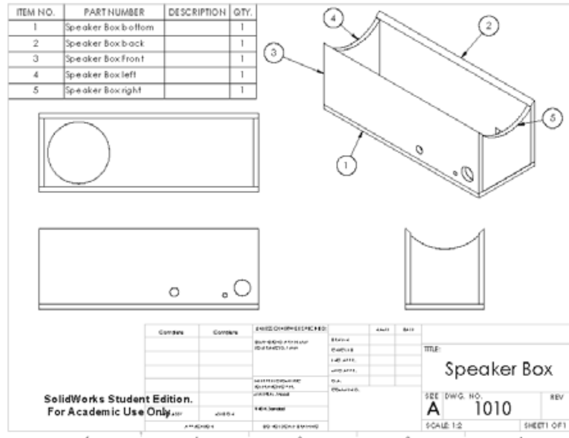
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For Academic Use Only.
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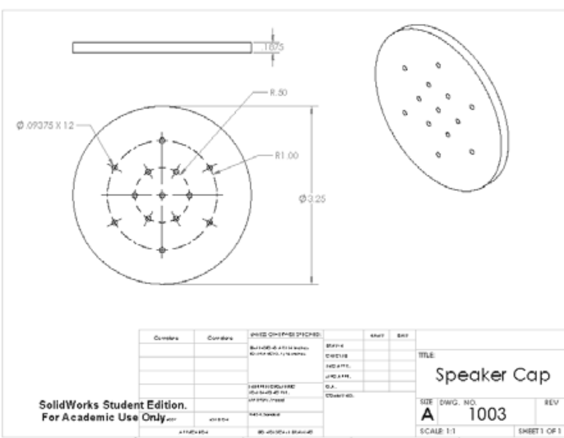
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R1.00
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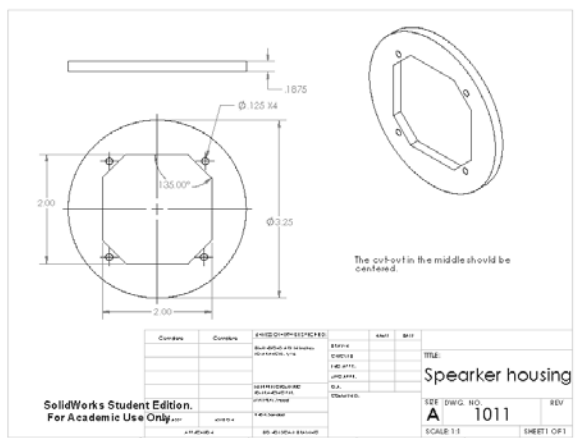
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Ø.125 X4
135.00°
2.00
Ø3.25
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For Academic Use Only.
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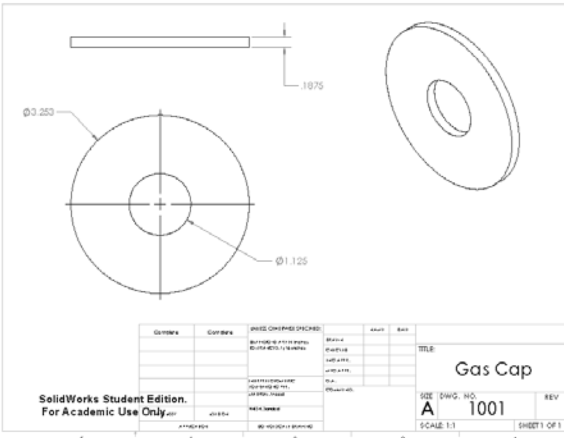
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Gas Cap
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For Academic Use Only.
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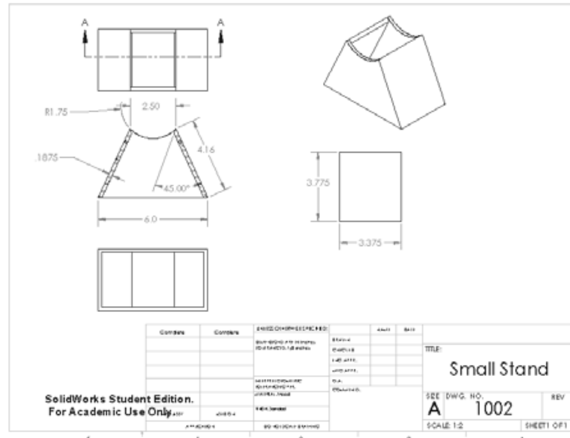
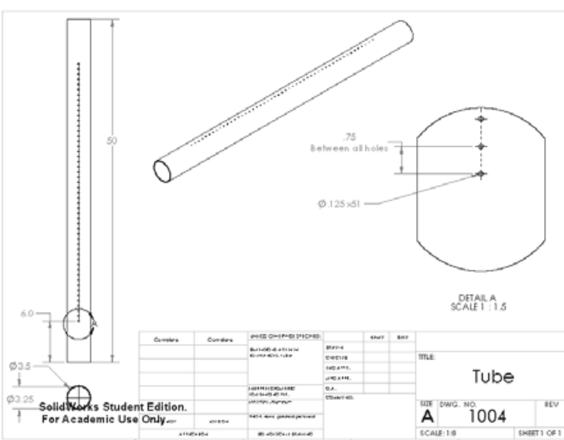
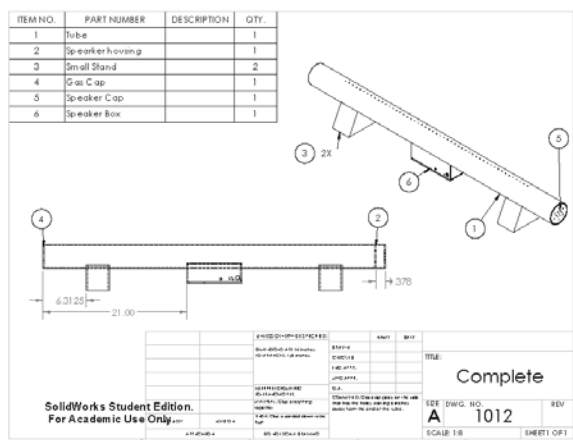
SCALE: 1:1
SHEET 1 OF 1


A
A
R1.75
2.50
.1875
4.16
45.00°
6.0
3.775
3.375
TITLE:
Small Stand
SolidWorks Student Edition.
For Academic Use Only.
SIZE DWG. NO.
A 1002
REV
SCALE: 1:2
SHEET 1 OF 1


50
.75
Between all holes
Ø.125 x51
DETAIL A
SCALE 1 : 1.5
6.0
Ø3.5
Ø3.25
TITLE:
Tube
SolidWorks Student Edition.
For Academic Use Only.
SIZE DWG. NO.
A 1004
REV
SCALE: 1:8
SHEET 1 OF 1


ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | Tube | | 1
2 | Spearker housing | | 1
3 | Small Stand | | 2
4 | Gas Cap | | 1
5 | Speaker Cap | | 1
6 | Speaker Box | | 1
2X
6.3125
21.00
.375
TITLE:
Complete
SolidWorks Student Edition.
For Academic Use Only.
SIZE DWG. NO.
A 1012
REV
SCALE: 1:8
SHEET 1 OF 1

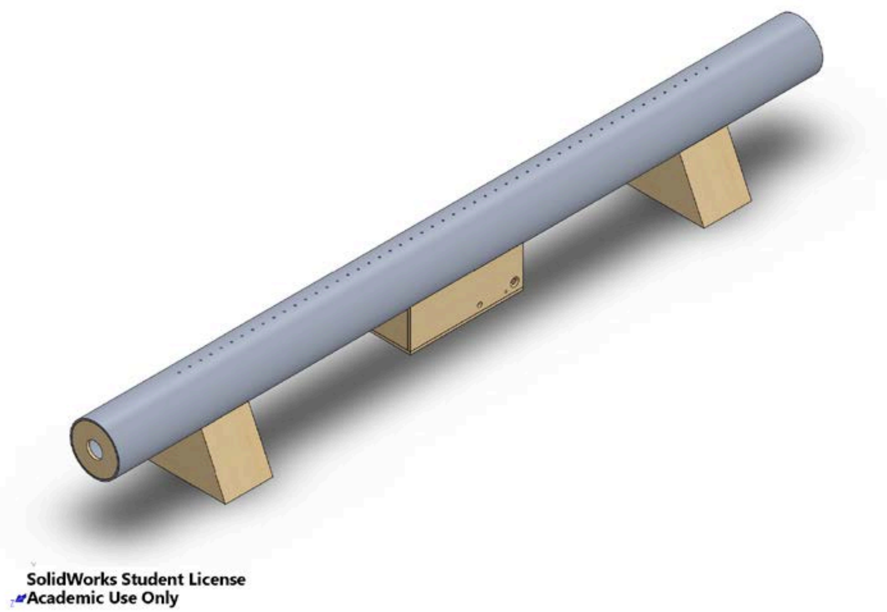


Figure 16: Isometric view of assembled product in Solidworks

Final Product

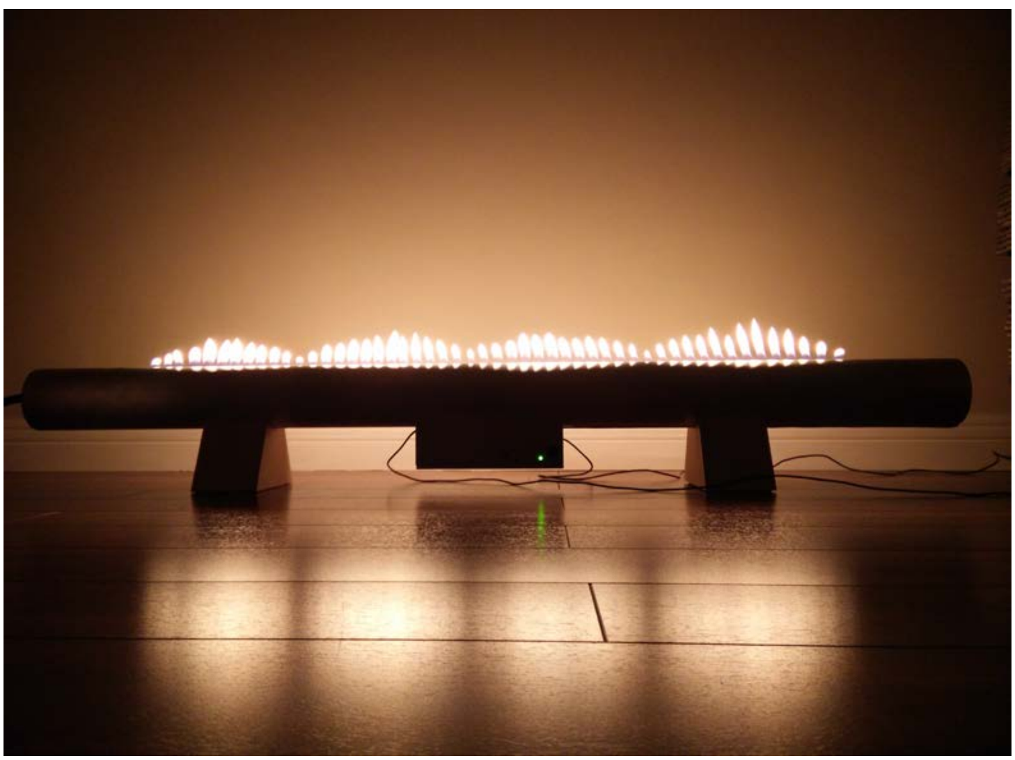


Figure 17: Rubens' tube responding to a pure sinusoid

Demonstration of the tube in action by playing the song "This Fire" by Lisa Miskovsky can be seen at:
https://www.youtube.com/watch?v=6oIC_EgapOQ

Modular Robotic Arm (ME 102b)

Project Description

For the Mechatronics Design course project, we designed and build a modular robotic system. The intended use was for applications that require repeated movements but also need flexibility due to a changing environment. Such a scenario could arise in small-scale manufacturing companies. Our group went over several possibilities, which lead to a final design where each linkage is responsible for a rotation and these linkages can be stacked on each other in the same orientation or rotated by 90 degrees.

Mechanical Design

As seen in *Figure 18*, the design was to construct a box shaped linkage that houses a high torque motor (2700 oz-in) and all of the electronics are housed internally. This allows for each unit to be replaced independent of the arrangement of the entire arm. Thus, a quick service can be made in case of mechanical failure.

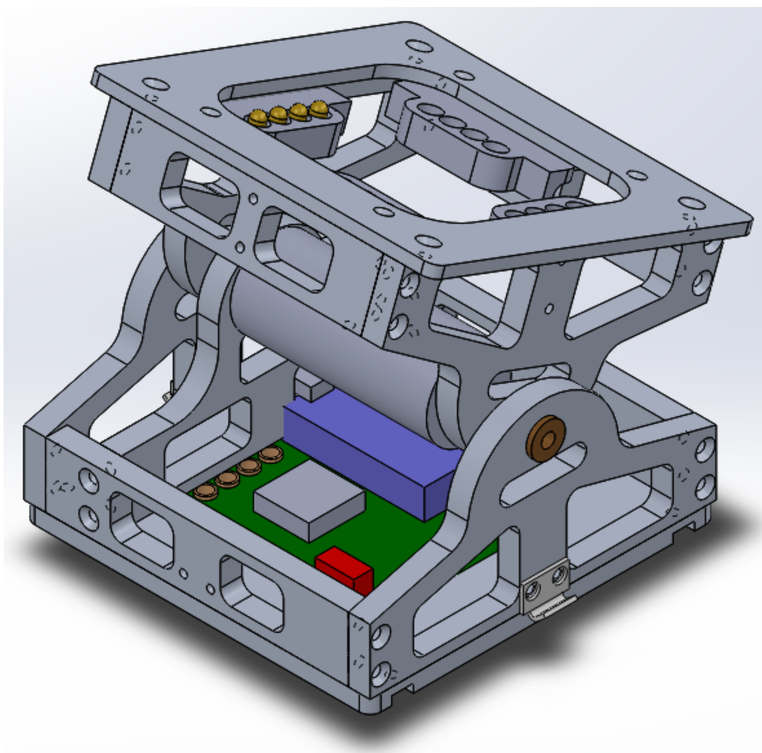


Figure 18: One linkage for modular robotic arm

Electrical Design

In order to keep the setup as modular as possible, each module had its own microcontroller (Arduino nano) which communicated to a central computing station (Raspberry Pi2) over I2C. In regards to the power delivery, all units were connected to a 36 V rail in order to minimize the current for the same power requirement which allows for thinner wires to be used. As a result, linear and switching regulators were used to step down the voltage to a safe level. The maximum expected power was computed for when 6 linkages are all stalled. A high-level schematic is shown below in *Figure 19*.

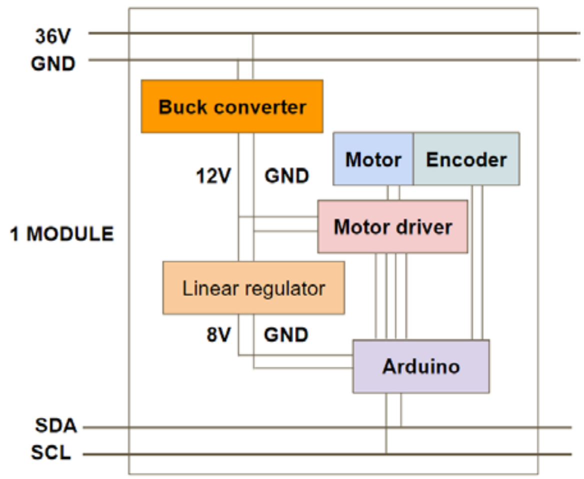


Figure 19: Electrical schematic of a single module

Final Product

The final electronics and complete project are shown in *Figure 20* and *21* respectively. Controlling the arm was done via a terminal on the Pi2, and motor controls were done with a PD controller. Additionally, the arm had other functionalities such as memorizing paths or executing paths defined a CSV file.

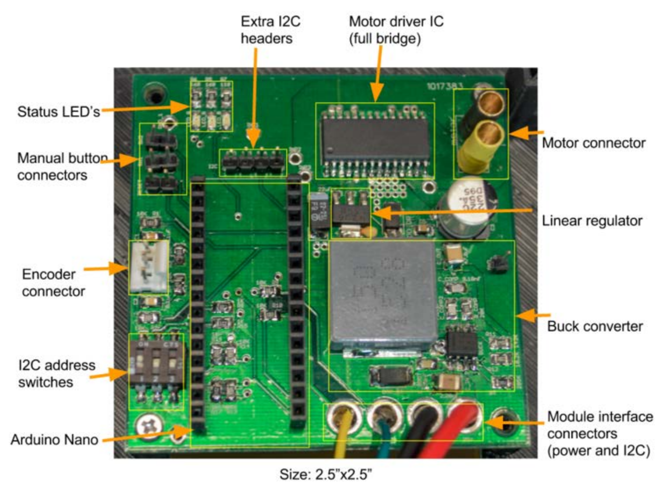


Figure 20: Final PCB housed in each unit

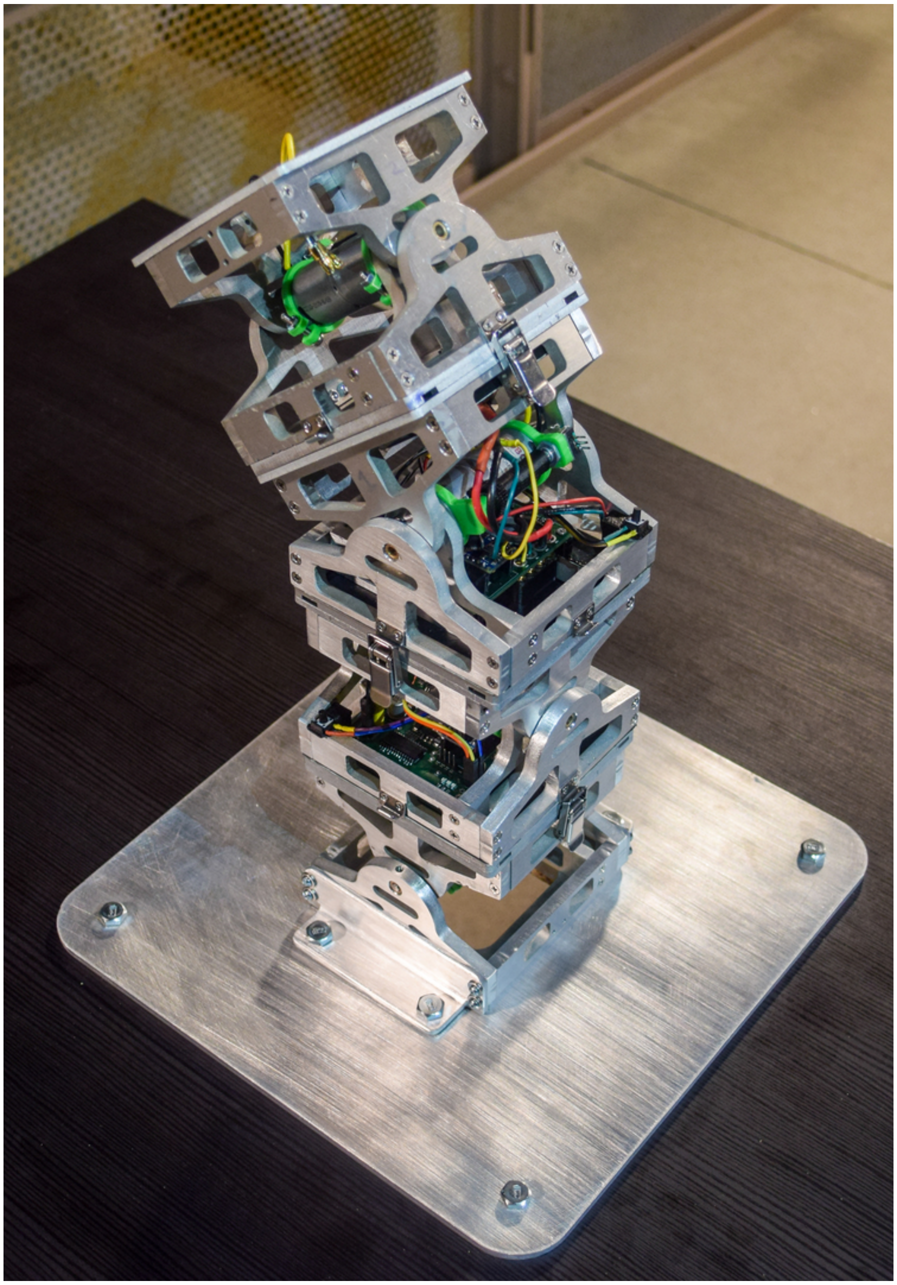


Figure 21: Completed modular arm

Lane Keeping with Obstacle Avoidance (ME 131)

Project Description

The goal of this project was to utilize the bicycle model of vehicles to perform a lane changing maneuver for an RC car in a closed loop. Additionally, an array of ultrasonic sensors were mounted to the body of the car to perform obstacle avoidance by changing lanes. When there were obstacles in all directions, the car would stop

Approach Taken

To accomplish this task, an analog line-scan camera was used for lane identification and, using a PD controller, the error between the desired lane location to the actual was brought as close to zero as possible. Concurrently, the readings from the ultrasonic sensors were being read via interrupts to determine if an obstacle is present. Once an obstacle is seen, the reference lane is changed in order to avoid the obstacle. To assess the performance of the lateral controller, a longitudinal PI controller was made to keep the car driving at a constant velocity. The entire system was executed on the system pictured in *Figure 22*. Code for this project can be found at

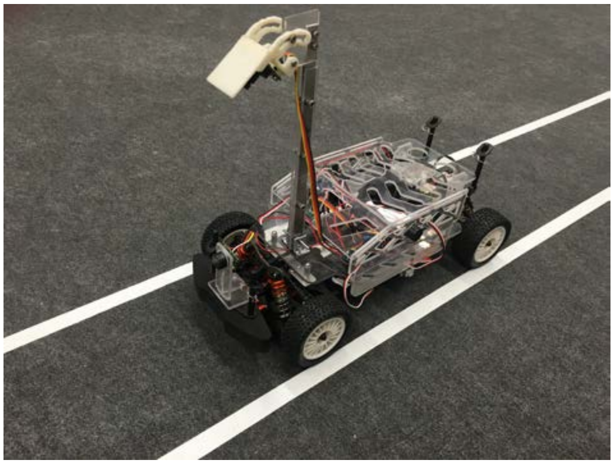


Figure 22: Car used for lane keepign and obstacle avoidance

Code for this project can be found at https://github.com/ych09041/me131lane.git, and a video demonstrating functionality at https://www.youtube.com/watch?v=5HKu7AaSsoM.

Adaptive Cruise Control (ME 107)

Project Description

The main goal of this project was to design an experiment that assess the performance of Adaptive Cruise Control (ACC) under varying weight and following distances. Two carts were made one to be the lead vehicle and the other the follow vehicle. A picture of the two is shown in *Figure 23* where the lead vehicle is the one on the left and the follow vehicle on the right. The lead vehicle was driven with a PI controller to achieve a constant velocity, and the follow car with a PID controller to achieve constant spacing with respect to back of the lead vehicle. The experiment was carried out at 0%, 10%, and 20% added weight at each following distance of 20 cm, 30 cm, and 40 cm

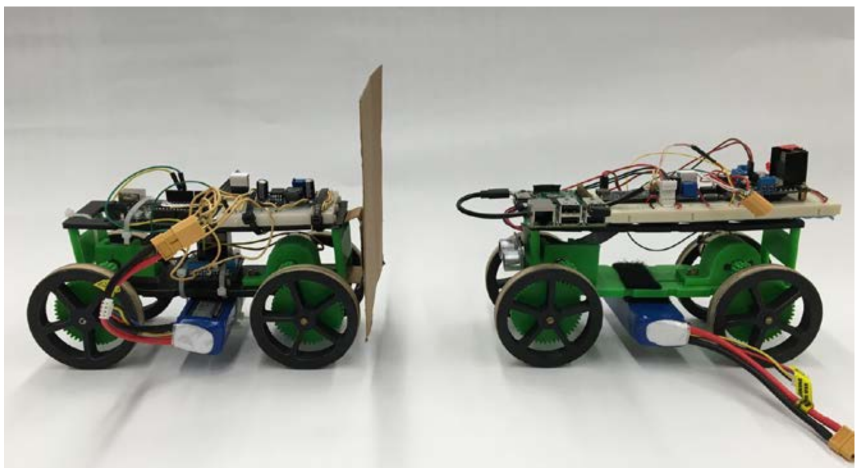


Figure 23: Lead and follow vehicles

Results

The result of the experiment on the amount of overshoot can be seen in *Figure 24*. As expected, increasing the weight of the car and reducing the following distance will increase overshoot for the same controller. Thus, different controllers need to be used for different conditions in order to ensure safety.

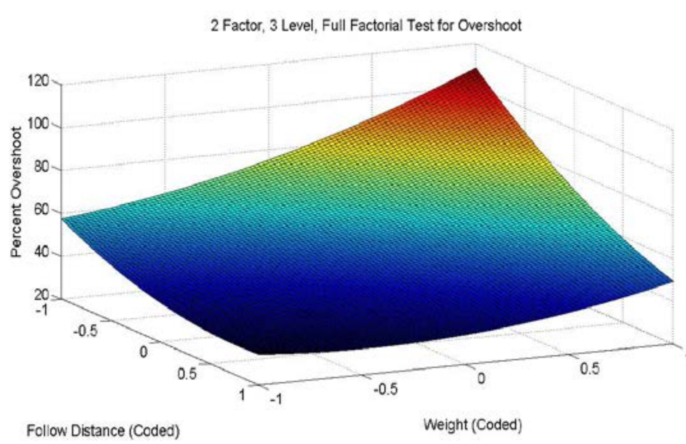


Figure 24: Relationship between weight and follow distance on amount of overshoot for ACC

Gesture Controlled Quadopter (EE 249)

Project Description

In this project, Quad X configuration drone was built on top of the APM 2.8 flight controller running the latest 3.2.1 firmware. Once built, python code was written to control the roll, pitch, and yaw angles as well as the throttle by getting feedback from the accelerometer, gyroscope and barometer onboard using a Leap Motion controller for gesture recognition. Communication was done over telemetry by using the droneKit wrapper. As a project for an embedded systems class, these goals were achieved with a methodical process by using concurrency via threads, having dynamic timing, and using broadcasters and listeners.

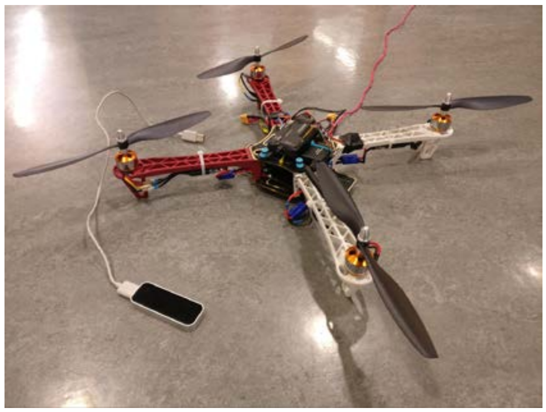


Figure 25: Drone with leap motion

The Copter

Building the quadcopter involved researching and understanding how these devices work in order to procure the right materials for construction. The two components that were salvaged from another quadcopter used in the past were the ESCs and motors due to monetary constraints. Unfortunately, the ESCs proved to be difficult to use since old SimonK firmware was flashed on them. Additionally, one of the ESCs was completely broken. As a result, a similar ESC was bought and all of the working ESCs were flashed with the latest BLHeli firmware that worked for the board. This was accomplished by using a USBAsp and soldering to the pads as shown in Figure 26. With the ESCs flashed, the hardware was up and running and tested using an RC controller.

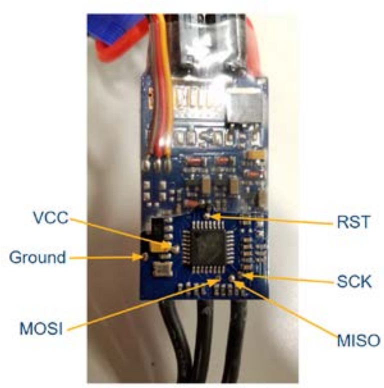


Figure 26: Pinout for flashing Spider 30A OPTO ESC

Control Logic

Controlling the quadcopter was done by using the telemetry to override the channel input of an RC controller, and sending computed values from a laptop. In order to control the roll and pitch angles of the quadcopter, feedback was used by the pre-integrated gyro data offered by the APM via droneKit using a proportional controller. Since the quadcopter was in stabilize mode, the RC channel values correspond to a roll and pitch angle. Thus, the feedback was very stable. Controlling yaw was slightly less stable since the same methodology was used, but this time the channel value corresponds to a yaw *rate* rather an absolute yaw angle. Thus, to improve stability, the maximum yaw rate was limited. Lastly, controlling throttle was done correlating the channel input to a desired acceleration. This acceleration is with respect to the global inertial frame. However, the acceleration values obtained from the quadcopter are with respect to its own noninertial body frame. Thus, a rotation matrix, found in Figure 27, was applied to the vector of body-fixed-frame acceleration values and proportional feedback was done on these values. The reference values were obtained by the Leap Motion where the relative height of the left hand corresponds to the throttle and the orientation of the right hand corresponds to the desired roll, pitch, and yaw angles. Testing each component was done in steps by having the Leap only control one axis at a time for safety purposes. A statechart depicting the high-level processes done by software is shown in Figure 28

$$\begin{bmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix}$$

Figure 27: 3D coordinate transformation with 3-2-1 basis

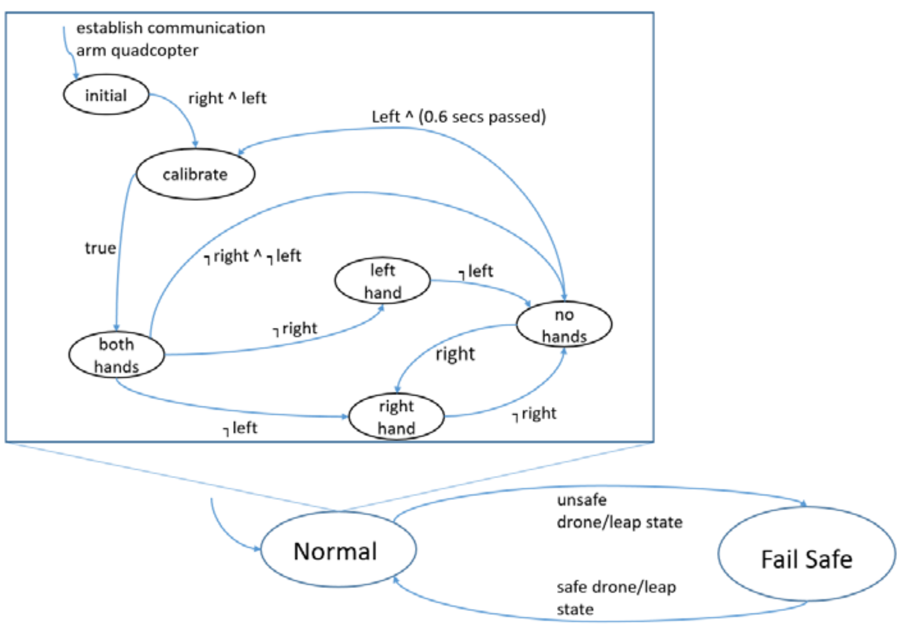


Figure 28: State chart of software architecture for gesture controlled drone

Code: https://github.com/arjunmehta94/EECS149project

Video: https://www.youtube.com/watch?v=9tlubUa04NE&feature=youtu.be

Robot Kitchen Assistant (EE 206a - Baxter)

Project Description

Utilizing the Baxter robotics platform, a kitchen assistant was created that would be given an instruction list such as cutting carrots or washing dishes and it would execute the tasks as efficiently as possible. The items to be picked up were not placed in the same position, rather AR tags were used to identify all items. Additionally, when items were moved, constraints were set in place to make sure no collisions occurred. An example environment is shown in Figure 29

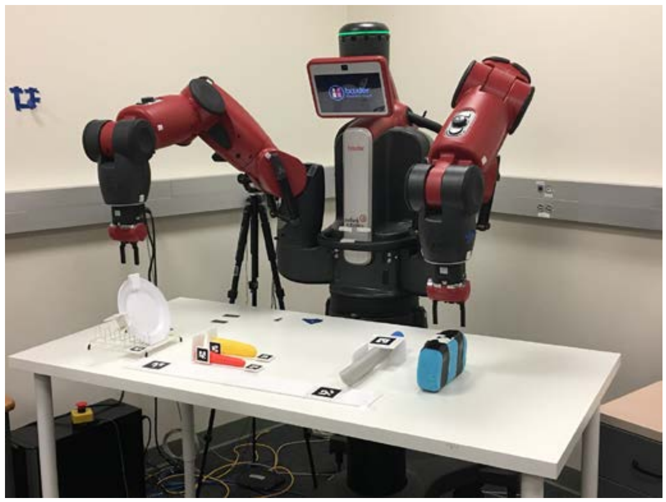


Figure 29: Environment of Baxter kitchen assistant

Identifying Objects

In order to locate items in the environment, objects were marked with AR tags and read by a camera facing the table. Since Baxter's arms or other items could interfere with the detection of an AR tags, AR bundles were used for robustness. An AR bundle is a grouping of AR tags which all reference the same position of a master AR tag. This ensures that occlusion won't be an issue. The ROS package that helped achieve this was AR_track_alvar. A visual representation of the bundles is shown in Figure 30.

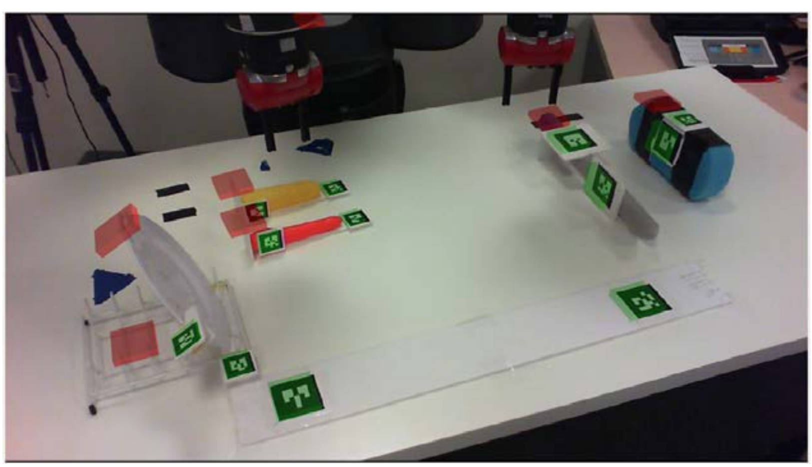


Figure 30: Visualizing the bundles

Avoiding Collisions

To improve robustness even more, collision avoidance was another challenge that was sought to be achieved. This was accomplished by using the Planning Scene Interface of moveit_commander to create a virtual representation of the physical environment that would then be used to by moveit_commander when computing the numerical inverse kinematics. A depiction of the physical environment in the Planning Scene is shown in Figure 31.

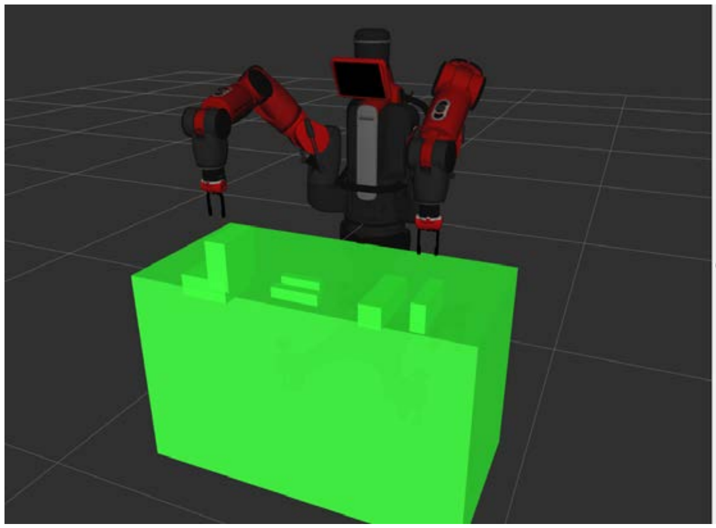


Figure 31: Representation of the environment in the obstacle world

Code: https://github.com/ych09041/ee206akitchen

Video: https://www.youtube.com/watch?v=RnBeRQ3_RMI

Line Following Car (EE 192)

Project Description

In this project I was tasked to construct a system from scratch that would follow a strip of white tape autonomously using a line-scan camera as quickly as possible. As a result, this project encompassed multiple areas of my studies including mechanical design, electrical design, and embedded programming. The finished product is shown below in Figure 32.

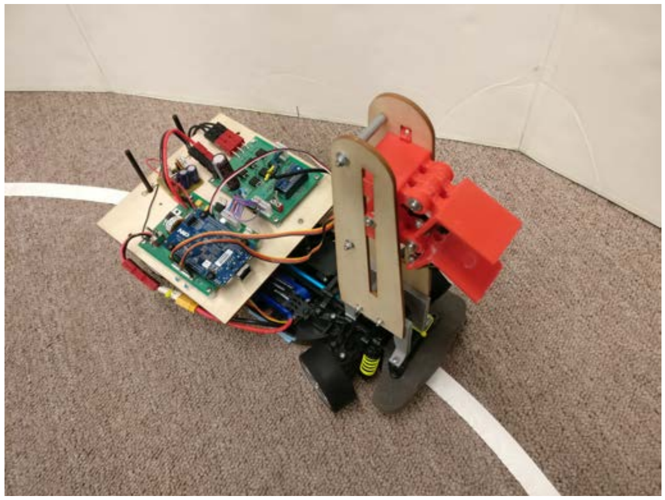


Figure 32: Finished car for EE 192

Electrical Design

The electrical components needed to make the car functional are the motors, line camera, steering, and onboard microcontroller logic. All these components in turn need to be operated from a single power source even though they might operate at different voltage levels. All these components were distributed onto two separate boards to reduce noise between high voltage and low voltage components in addition to making future modifications easier. Since the motor controller was the only high voltage component, it was isolated on a dedicated board and can be seen on the next page in Figure 33. This board features very large traces with as few "squares" as possible to reduce copper loss from the large currents running through the motor at stall torque. Additionally, the power MOSFETS utilize the copper in the PCBs for extra surface area to improve cooling.

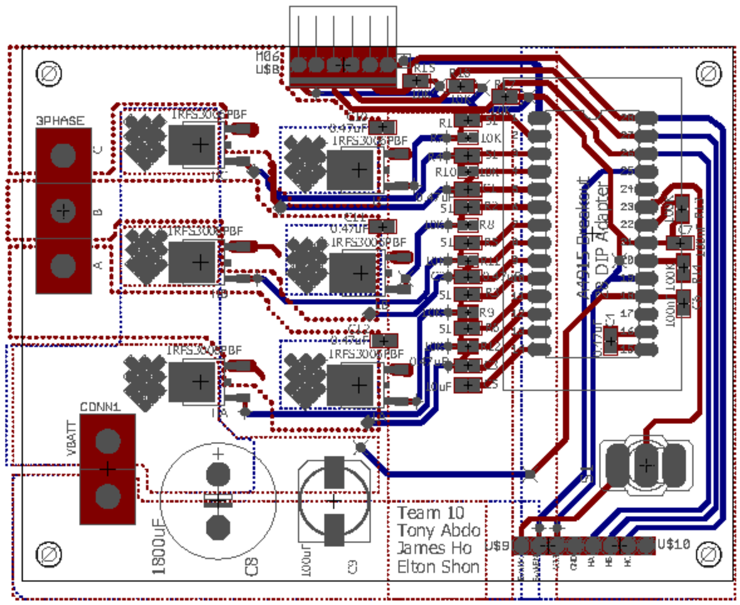


Figure 33: Motor controller board for car

The second board houses the voltage regulation components, micro controller, and camera connectors. The 3-cell LiPo (11.7V nominal) is stepped down to 5V using a switching regulator (LM2678S) to power the K64F and then stepped down again to 3.3V using a linear regulator (LM3940) to power the camera and the micro controller on the motor controller board. A layout of the board can be found in Figure 34. The complexity of this board was not great; however, there was an important factor to consider which was the placement of the switching regulator. The components, such as capacitors inductor, need to be close to one another and the input source to minimize noise from the very high switching rate of the regulator.

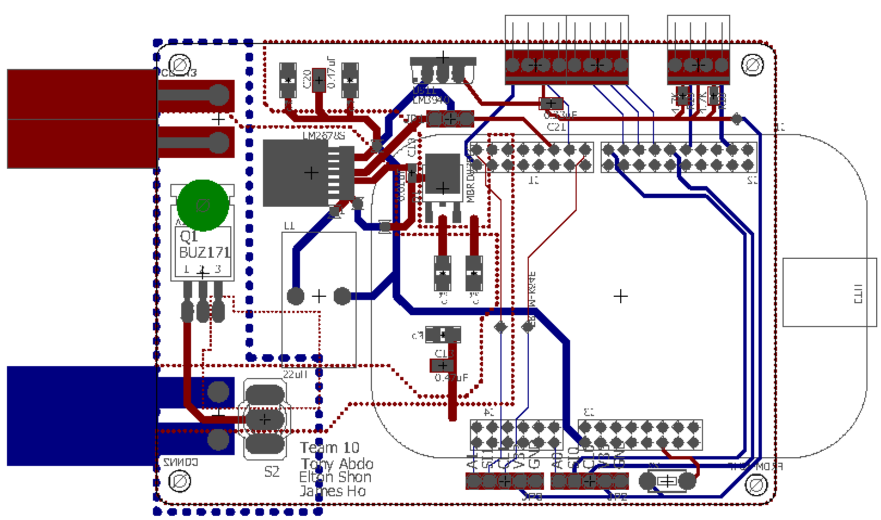


Figure 34: Board housing all other components

Mechanical Design

In order to make the control of the system as simple as possible, the mechanical components need to be designed to reduce any instabilities. For instance, having a center of gravity situated extremely high can cause large rolling behavior when cornering. Thus, creating a platform for electrical components very low and close to center of gravity was one of the design objectives. Additionally, the camera mount was constructed out of plywood since it is cheap, quick to manufacture, and rigid to minimize undesired rolling effects. Another concern was a rigid camera holder since any movement of the camera (especially pitching) can greatly impact the image quality. However, the design would need to be flexible in the sense of allowing a vertical degree of freedom. As a result, the resulting design had a large joint that had multiple faces in contact for redundancy. The size of the joint allowed for a large compressive frictional force. To allow for a vertical degree of freedom, slots were used for the side panels (which prevented lateral motion) and the side panels were used to provide a large clamping to prevent movement.

Integration

All these components were integrated together as depicted by Figure 35. The primary goal in the integration of each electrical component was to abide by a star configuration since this kind of configuration would mitigate noise from high frequency switching components.

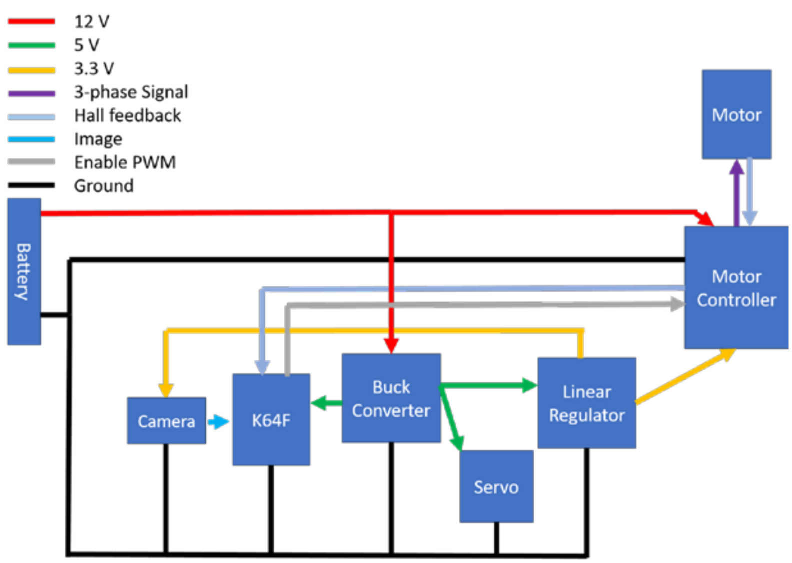


Figure 35: System overview of all components on the car

Autonomous Control

To control the car autonomously, feedback control was implemented for both velocity and steering. Velocity control was implemented with PI controller at the low level. Additionally, a higher level protocol of changing the reference velocity was employed to improve stability when turning. Velocity estimation was done by counting the number of rotations of the motor via hall effect sensors in a fixed time period. The steering control was implemented using a PID controller using data obtained from the 128 pixel line camera. The image was analyzed with threshold and width detection to estimate the line center. Both velocity and steering control were synchronized to run at 200 Hz using time interrupts.

Results

The final product was ran on a track with many glare spots and a slippery floor with an average speed of ~6 ft/s. The stability of the car on this track can be seen in Figure 36. As can be seen, the response was nearly instantaneous for two successive step references.

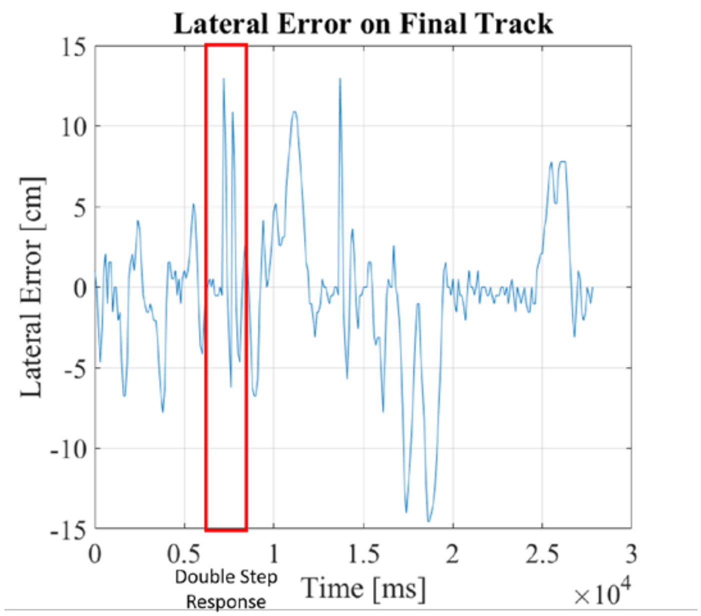


Figure 36: Lateral error on final track