Team 2 Technical Manual v.2

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    c. Resistors
    d. Diodes
    e. Terminals
    f. Op Amp

The circuit and the specs of the components for the power amplifier is provided in the appendix.

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3. 24 V Rechargeable Batteries (x2)
4. Rotary Encoder (x2)
5. DC Motor (x2)
6. IMU
7. Arduino UNO
8. Series 1 XBee w/ Antenna (x2)
9. XBee Explorer
10. Joystick (x2)

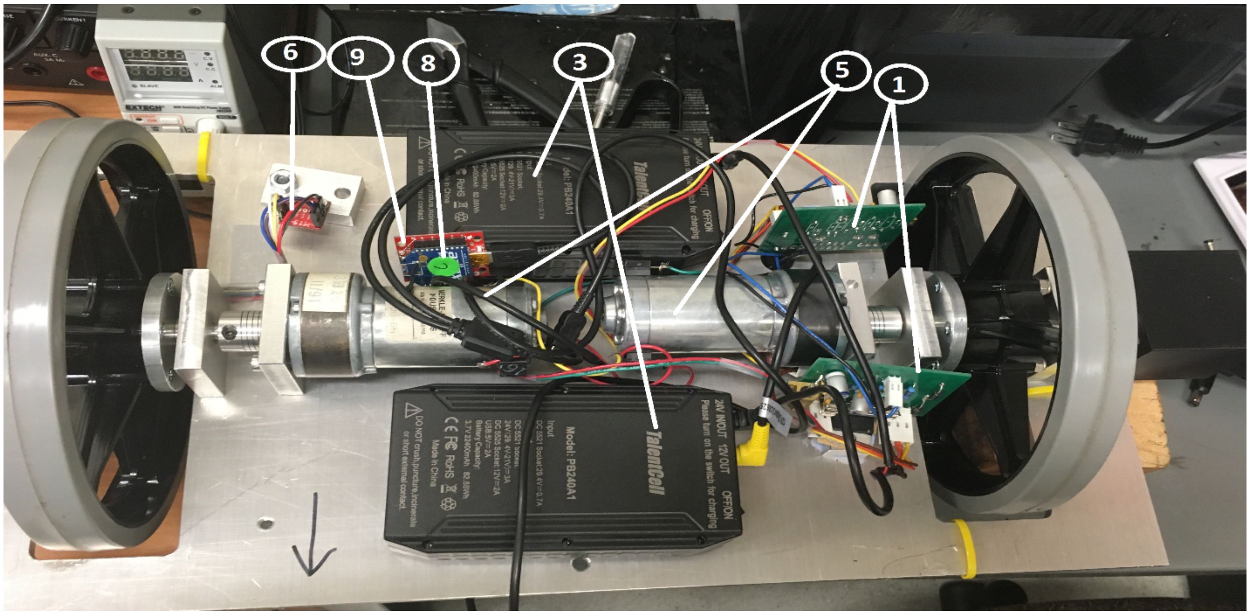


Figure 1: Top View of Robot Components

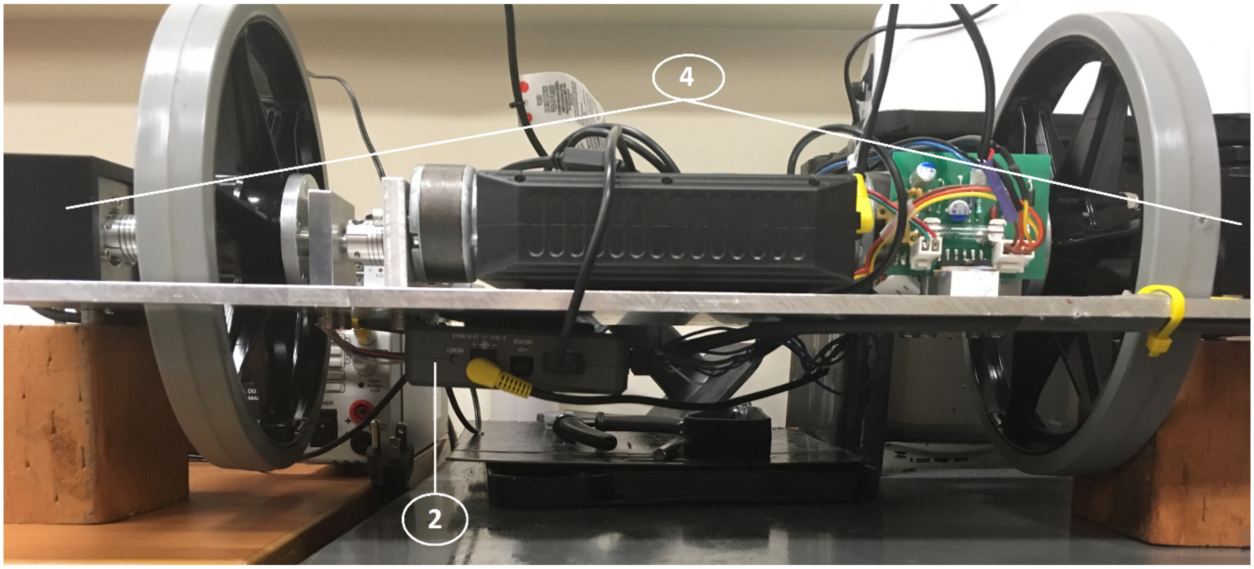


Figure 2: Side View of Robot

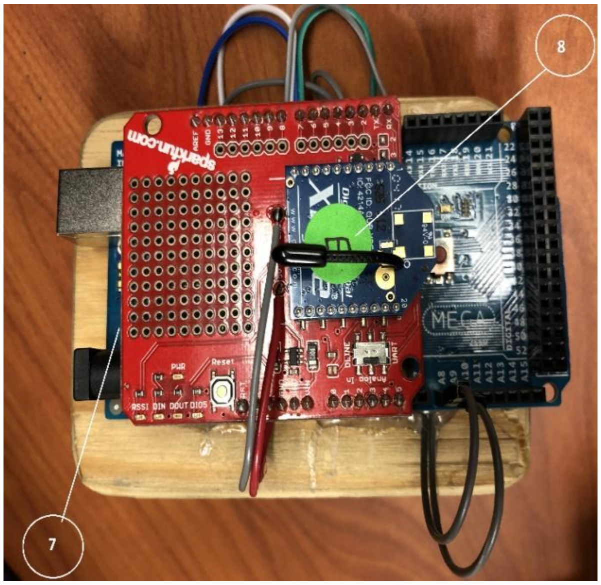


Figure 3: XBee and Arduino Uno

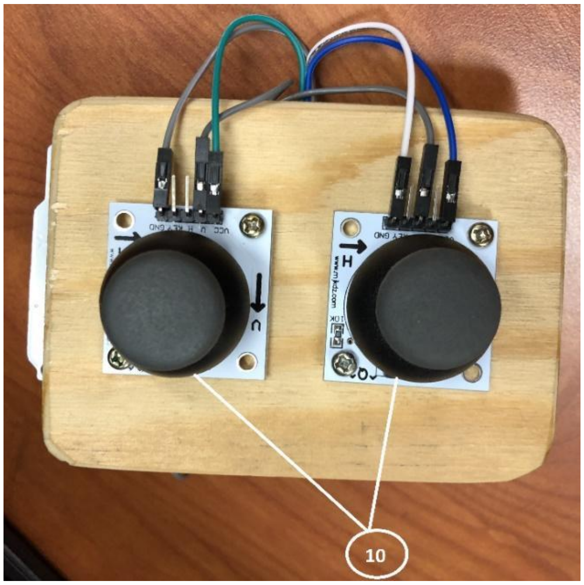


Figure 4: Joystick Controls

Software

1. LabView myRIO toolkit
2. Arduino IDE
3. XCTU

Specification Document (Rafi Marandi and Kristen Venditti)

Power Amplifier

1. Capacitor (470pF, 0.1µF, 47µF)
2. Resistors (2.2, 1.5k, 3.32k, 12k, and 30.1kΩ)
3. Diodes (STTH208 fast recovery diodes)
4. Fuse (5 amp)
5. Connections (2/3/4 pin headers)
6. Op amp OPA549

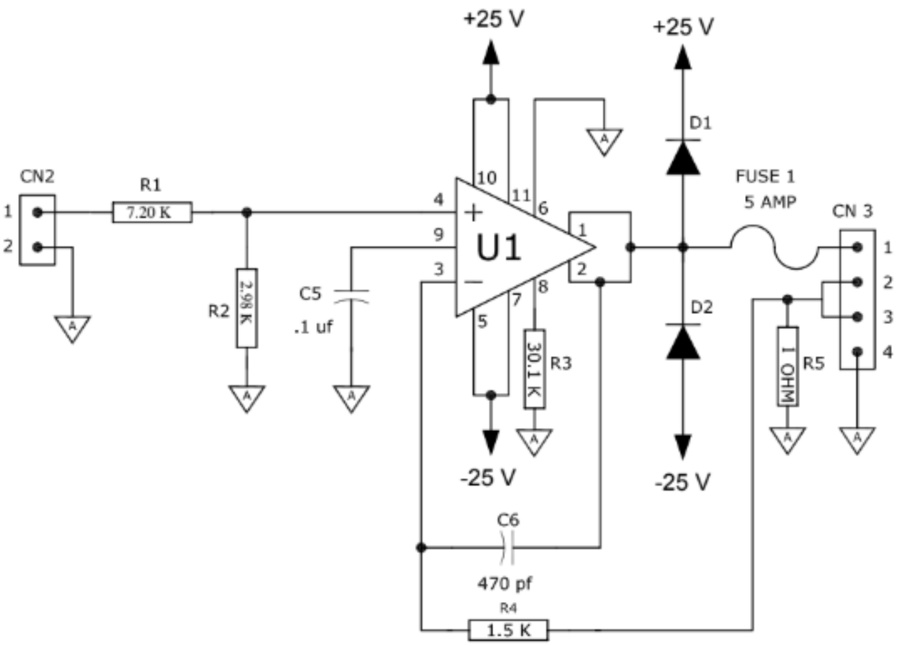


Figure 5: Power Amplifier

myRIO 1900

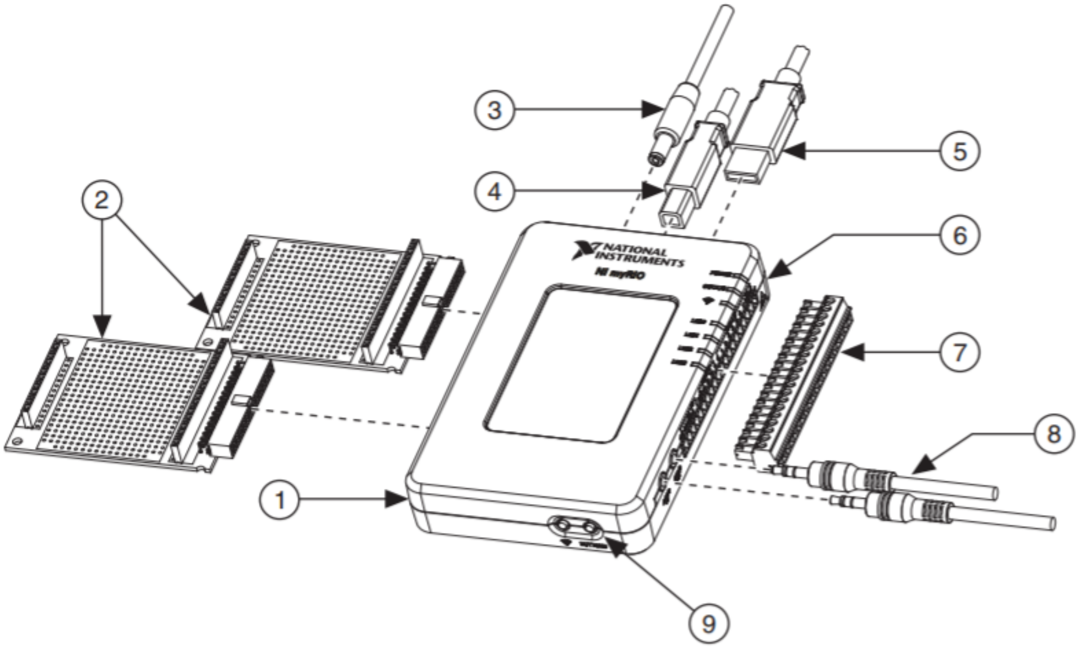
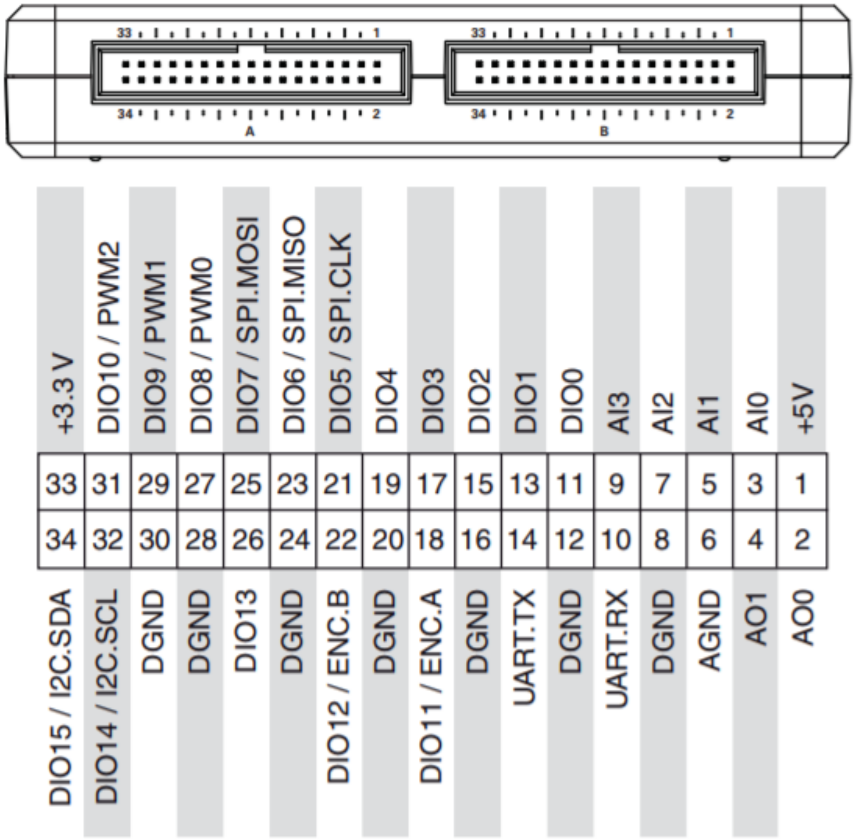


Figure 6: myRIO 1900

1. NI myRIO-1900
2. myRIO expansion port
3. Power input cable

4. USB device cable
5. USB host cable
6. LEDs
7. Mini system port (MSP
8. Audio in/out cables
9. Button



Pin	Signal	Pin	Signal
33	+3.3 V	34	DIO15 / I2C.SDA
31	DIO10 / PWM2	32	DIO14 / I2C.SCL
29	DIO9 / PWM1	30	DGND
27	DIO8 / PWM0	28	DGND
25	DIO7 / SPI.MOSI	26	DIO13
23	DIO6 / SPI.MISO	24	DGND
21	DIO5 / SPI.CLK	22	DIO12 / ENC.B
19	DIO4	20	DGND
17	DIO3	18	DIO11 / ENC.A
15	DIO2	16	DGND
13	DIO1	14	UART.TX
11	DIO0	12	DGND
9	AI3	10	UART.RX
7	AI2	8	DGND
5	AI1	6	AGND
3	AI0	4	AO1
1	+5V	2	AO0

Figure 7: MXP Connectors A and B of myRIO

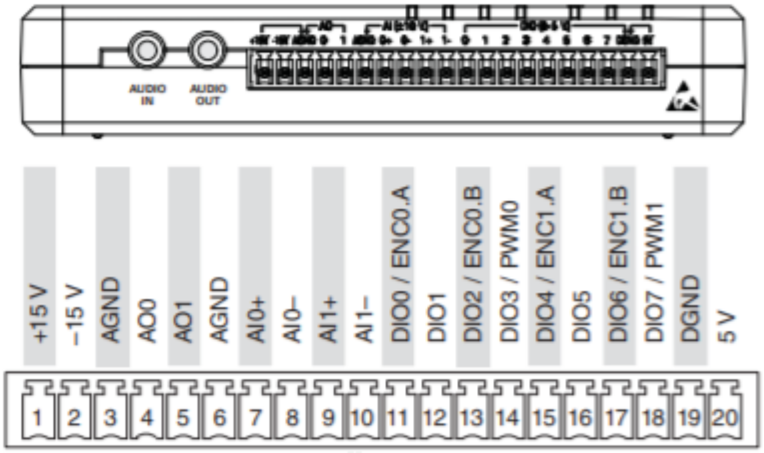


Figure 8: MSP Connector C of myRIO

Battery

- TalentCell Battery PB240A1
- Rechargeable Lithium ion battery pack
- Output: 24 V / 3 A Max and 12 V / 2 A Max
- Capacity: 3.45 Ah
- Weight: 1.4 lbs
- Dimensions: 8” x 4.1” x 2.2”

Figure 9: TalentCell Battery

Rotary Encoder

- Incremental 40-mm-dia. Rotary Encoder E6B2- CWZ3E
- Power supply voltage: 5 VDC −5% to 12 VDC.
- Current consumption: 100mA max.
- Resolution (pulses/rotation): 1024

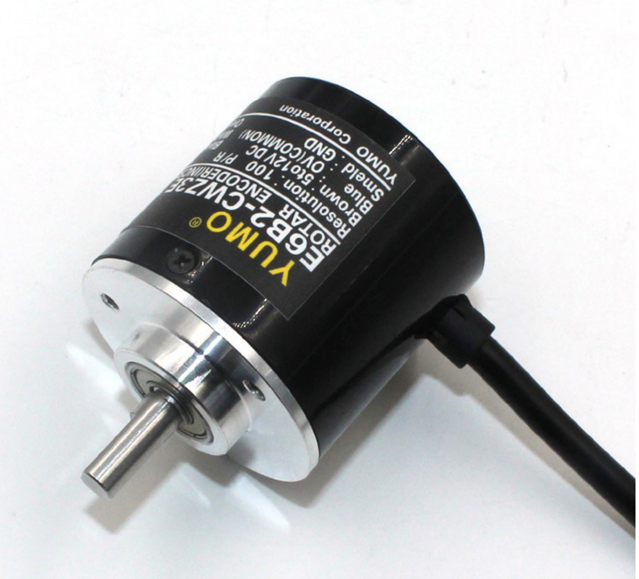


Figure 10: Rotary Encoder E6B2- CWZ3E

DC Motor

- Merkle-Korff Industries Motor
- Brush 24 VDC / 3 A Motor with internal gearbox

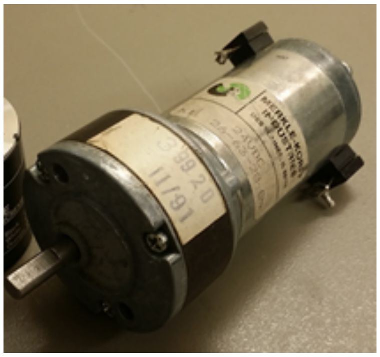


Figure 11: DC Motor

IMU

- SparkFun IMU Breakout - MPU-9250
- Digital-output triple-axis accelerometer
- Measurement range: ±2g /±4g /±8g /±16g
- 16-bit ADC

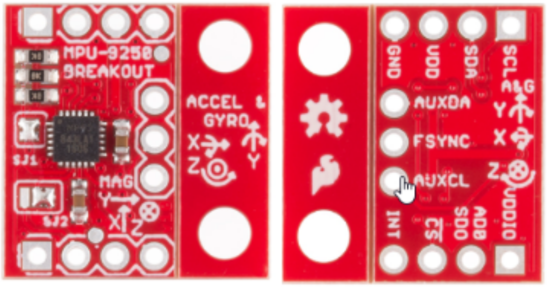


Figure 12: MPU 9250 IMU

Arduino UNO

- Microcontroller: ATmega328P
- Operating voltage: 5 V
- Input voltage: 7-12 V
- Digital I/O pins: 14
- PWM Digital I/O pins: 6
- DC current per I/O pin 20 mA
- Clock speed: 16 MHz
- Dimensions: 68.6 mm x 53.4 mm
- Weight: 25 g

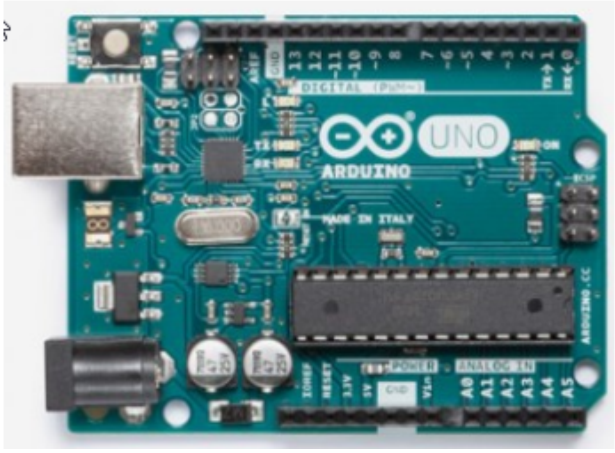


Figure 13: Arduino UNO

XBee Radio Module (Larry Lardieri, Omer Mucahit)[1]

- Indoor range: 30ft (tested value)
- Outdoor range: 60ft (tested value)
- Transmit power output: 1 mW
- RF data rate: 250,000 bps
- Serial interface data rate: 1200 bps - 250 kbps
- Receiver sensitivity: -92 dBm

[1] *v.2* Omar and Larry: Updated to reflect tested ranges and future development ideas.

- Power supply voltage: 2.8 - 3.4 V
- Transmit current: 45 mA (@3.3 V)
- Idle current: 50 mA (@3.3 V)

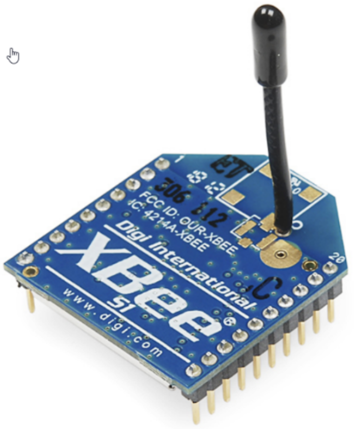


Figure 14: XBee S1 RF Module

Future Development Ideas:

- Xbee runs on 3.3V logic. If Joysticks are supplied with 3.3V from Xbee, arduino can be eliminated. Xbee must be used as AP mode. It has analog reading implemented inside.
- Instead of using Xbee, RF controller can be used. It will have longer range than stock Xbee. This option is only viable if one way data transmission is used.
- Wiring can be optimised and controller case can be printed with any 3-d Printer. Printing material can be PLA, PETG or ABS. PETG is recommended due to easiness of print and higher plastic transition temperature.

Joystick

- Two 10k potentiometers (for x- and y-axis)

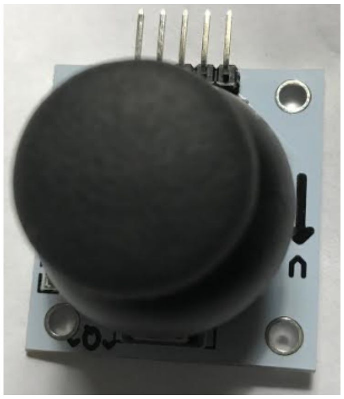


Figure 15: Joystick

Wiring of Components (Rafi Marandi and Kristen Venditti)

Motors to Power Amplifiers

1. Connect positive pole of the motor to connection 3 pin 1 on the power amplifier.
2. Connect negative pole of the motor to connection 3 pin 2 on the power amplifier.

Power Amplifier to Batteries

3. Connection 1 on the power amplifiers has pins 1, 2 and 3, which are negative, positive and ground respectively. Each of the pins from the power amplifier from 1, 2, and 3 are connected together and then connected to the batteries negative, positive and ground.

Power Amplifiers to myRIO

- Connection 2 on the power amplifier has pins 1 and 2, which are positive and negative respectively. Pin 1 of right power amplifier goes to Connector C of myRIO pin 5 and pin 1 of left power amplifier goes to Connector C of myRIO pin 4. Both power amplifier's pin 2 connect to Connector C of myRIO pin 3.

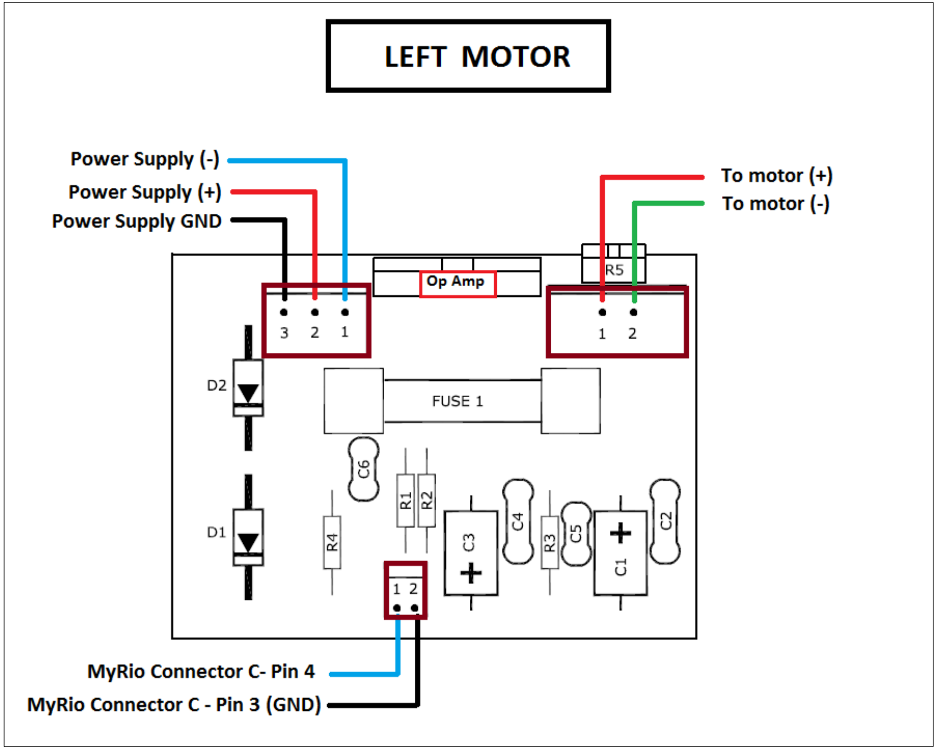


Figure 16: Power Amplifier Connections Diagram for Left Motor

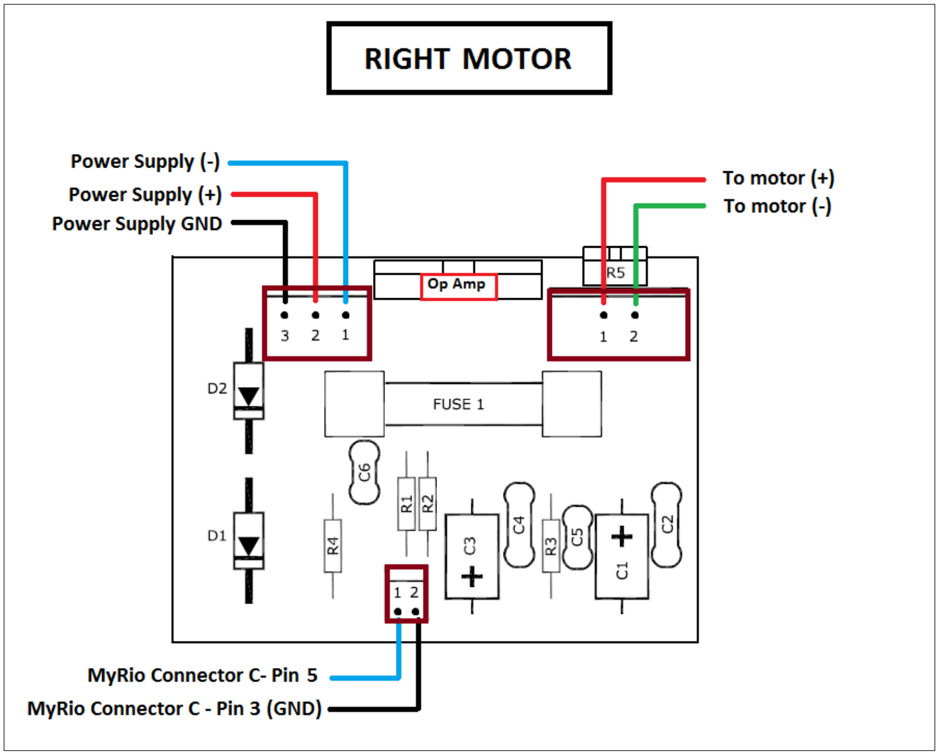


Figure 17: Power Amplifier Connections Diagram for Right Motor

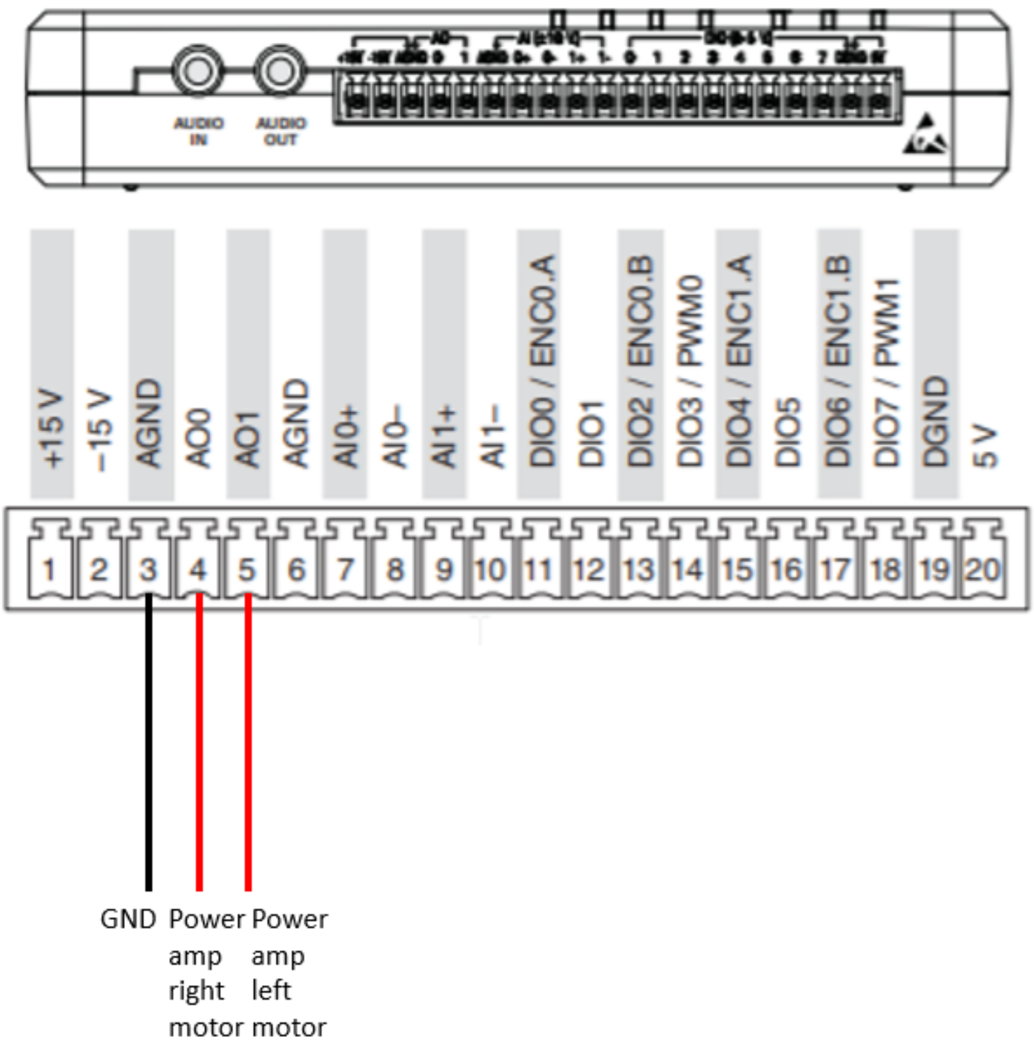


Figure 18:Wiring diagram for power amplifiers to myRIO

Encoders to myRIO

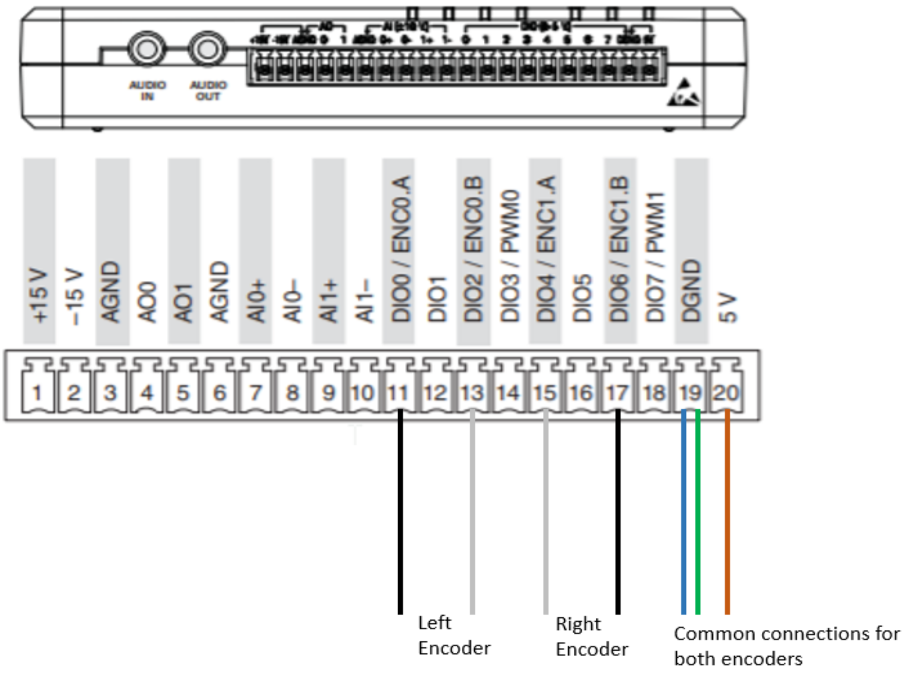


Figure 19: Wiring diagram for encoders to myRIO

IMU to myRIO

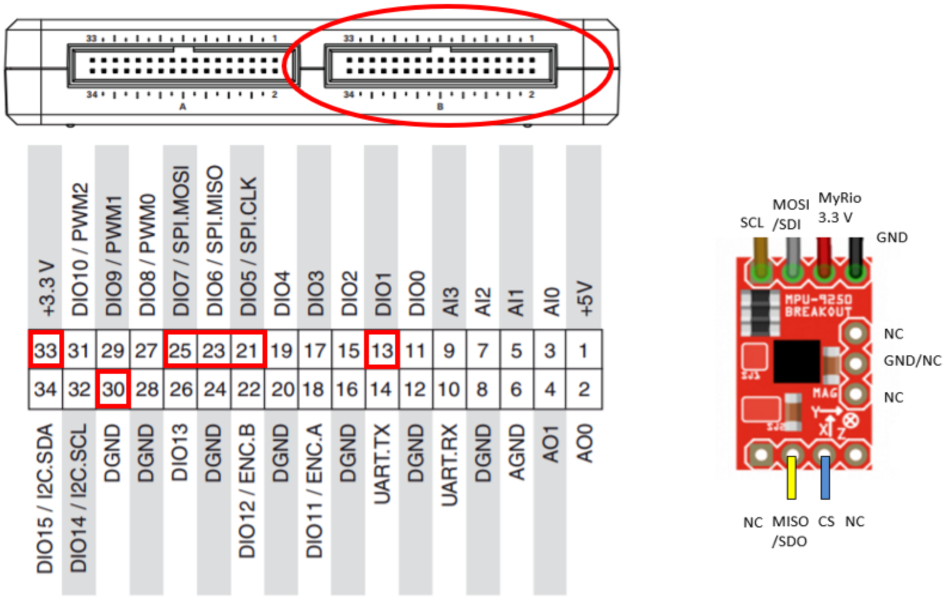


Figure 20: Wiring diagram for IMU to myRIO

Joystick and XBee to Arduino

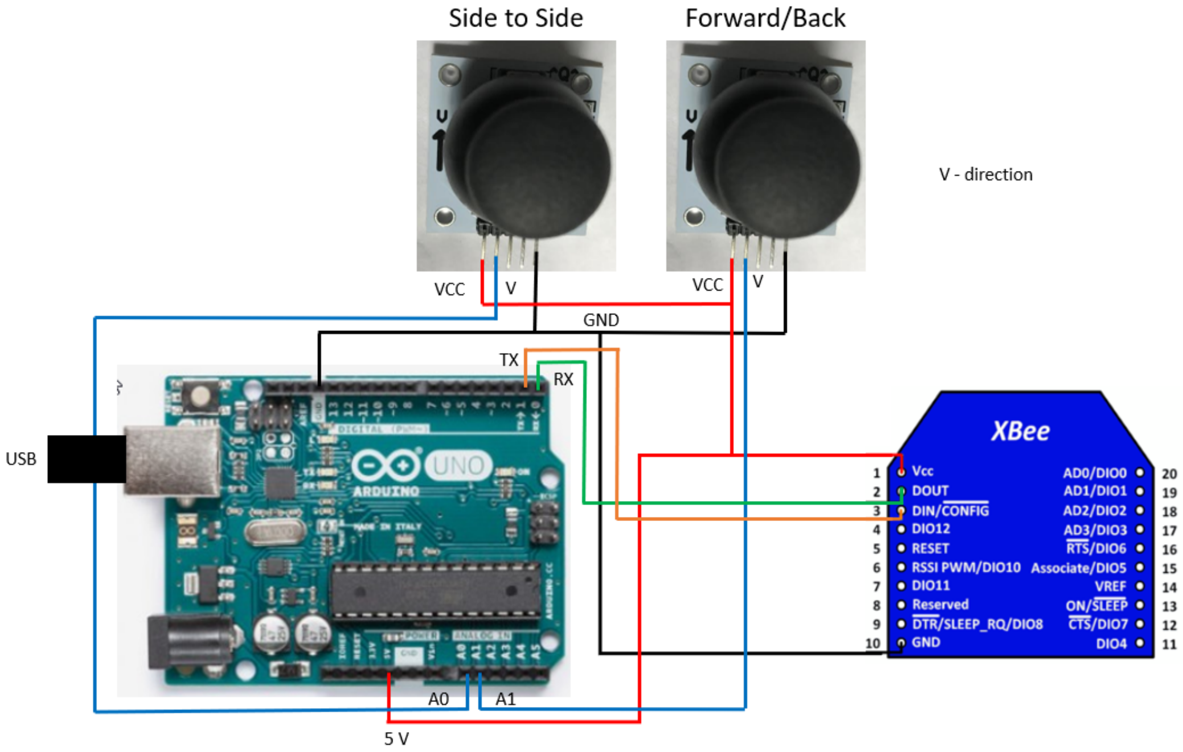


Figure 21: Wiring diagram for Joystick, XBee and Arduino

Design Document

Mechanical Design (Brendan Cook and Eric Holakiewicz)

The baseplate, as shown in Figure 22, was manufactured using 0.25in thick 6061 Aluminum plate. It is the chassis that all the components of the robot mount to. One (1) baseplate was manufactured and the manufacturing drawing is in Appendix A.

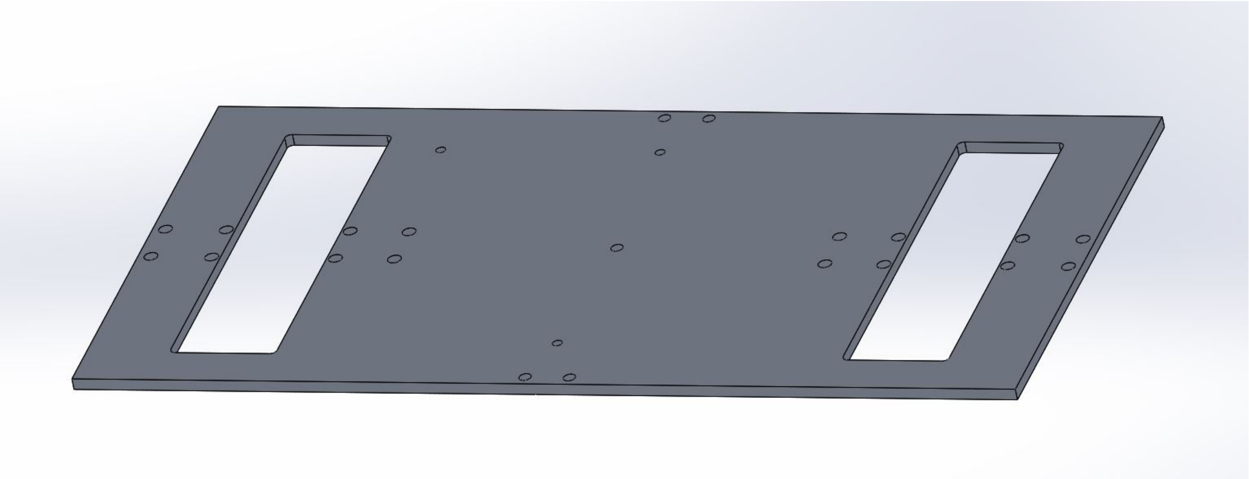


Figure 22: Baseplate

The bearing housing, as shown in Figure 22, was manufactured using 6061 Aluminum. It is used to house a standard skateboard bearing, which is used to support the drive shaft and allow rotation of the drive shaft. The bearing housing is mounted to the baseplate, as shown in Figure 1, using 0.5in long ¼ - 20 socket head screws. Four (4) of the bearing housings were manufactured and the manufacturing drawing is shown in Appendix A.

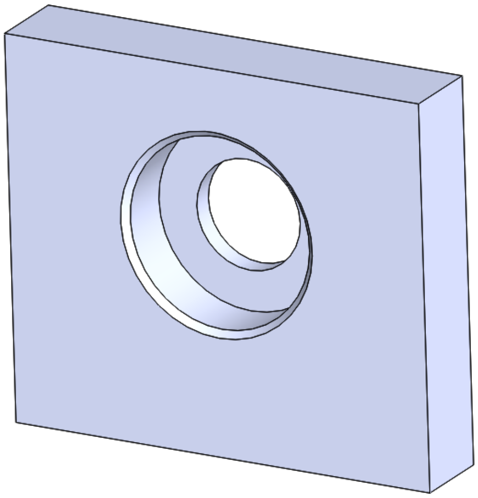


Figure 23: Bearing Housing

The flexible couplers, as shown in Figure 24, are used to connect the motor to the drive shaft, and the encoder to the drive shaft. Two different size couplers were used. One flexible coupling had a 0.25in diameter on one side and 8mm on the other, which was used to connect the motor to the drive shaft. The other flexible coupling had a 6mm diameter on one side and 8mm on the other, which was used to connect the encoder to the drive shaft. Two (2) of the 0.25in to 8mm flexible couplers and two (2) of the 6mm to 8mm flexible couplers were used. The flexible couplers were purchased from Servocity.com.

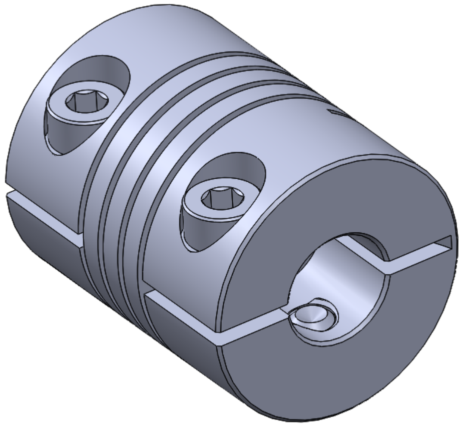


Figure 24: Flexible Coupling

The drive shaft, as shown in Figure 25, was manufactured using 6061 Aluminum and is used to connect the 8in plastic wheel to the motor and the encoder. The 8in plastic wheel is attached to the drive shaft using six (6) 1.75in long 8-32 Phillips flat head countersink machine screws with 8-32 hex nuts. The motor and the encoder are attached the drive shaft using the flexible couplers described previously. Two (2) of the drive shafts were manufactured and the manufacturing drawing is shown in Appendix A.

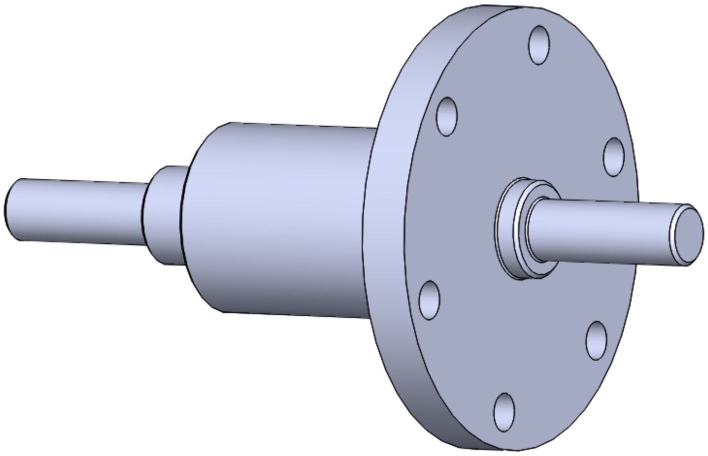


Figure 25: Drive Shaft

The encoder, as shown in Figure 26 is an Omron E6B2-CWZ6C incremental 40mm diameter rotary encoder. The encoder is used to measure the rotation of the drive shaft. The encoders are connected to the drive shaft using the flexible couplers discussed previously, and the encoders are mounted to the baseplate using the encoder mounts (Figure 7), which is discussed later. Two (2) encoders were used.

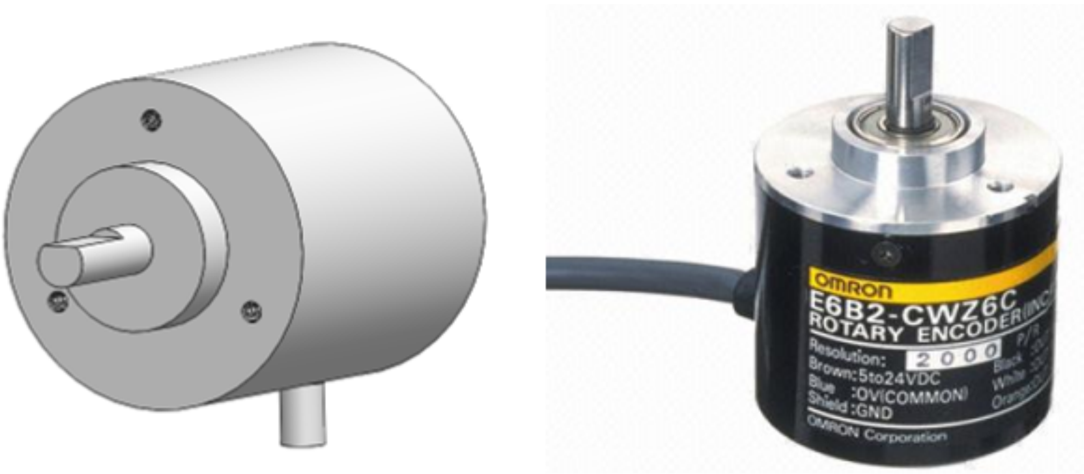


Figure 26: Encoder

http://www.globalsources.com/si/AS/Kwoco-Automation/6008847576041/pdtl/E6B2-CWZ6C-OMRON-rotary-encoder-sensor/1061361307.htm

The encoder cover, as shown in Figure 26, was manufactured using ABS plastic on a rapid prototyping 3D plastic printer. The encoder cover is used to protect the encoder from being damaged while driving the Robot. The encoder cover slides onto the encoder mount using the groove on the inside of the encoder cover as shown in Figure 6 and Appendix A. Two (2) encoder covers were manufactured, and the manufacturing drawing is shown in Appendix A.

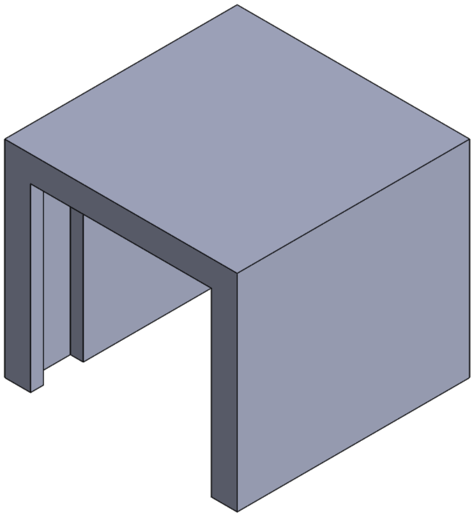


Figure 27: Encoder Cover

The encoder mount, as shown in Figure 28, was manufactured using 6061 Aluminum and is used to attach the encoder to the baseplate. The encoder was mounted to the encoder mount using three (3) M3 X 0.5mm screws. The encoder mount was mounted to the baseplate using 0.5in long ¼ - 20 socket head screws. Two (2) of the encoder mounts were manufactured and the manufacturing drawing is shown in Appendix A.

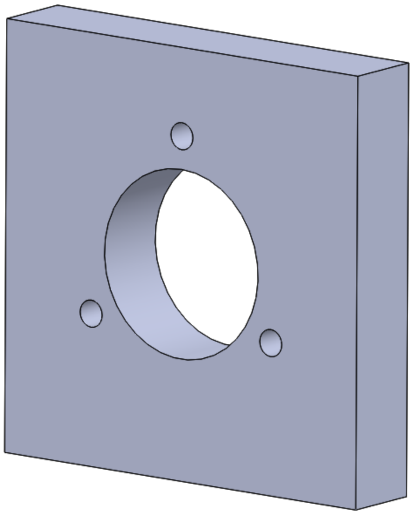


Figure 28: Encoder Mount

The motor, as shown in Figure 29, is a 12V DC electric planetary gearmotor.[2] The motor is used to rotate the drive shaft to move the robot. The motors are connected to the drive shaft using the flexible couplers discussed previously, and the motors are mounted to the baseplate using the motor mounts, which is discussed later. Two (2) motors were used.

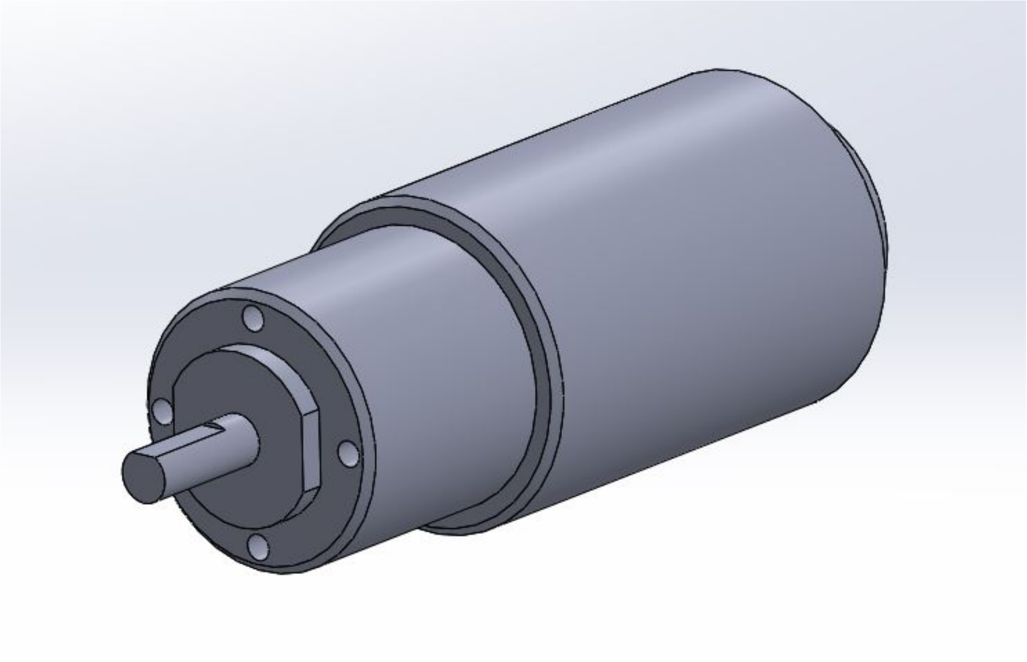


Figure 29: DC Motor

The motor mount, as shown in Figure 30, was manufactured using 6061 Aluminum and is used to attach the motor to the baseplate. The motor was mounted to the motor mount using four M3 x 0.5mm x 12mm phillips head screws. The motor mount was mounted to the baseplate using 0.5in long ¼ - 20

[2] *v.2* James: Updated to reflect new motors, mounts, and assemblies.

socket head screws. Two (2) of the motor mounts were manufactured and the manufacturing drawing is shown in Appendix A.

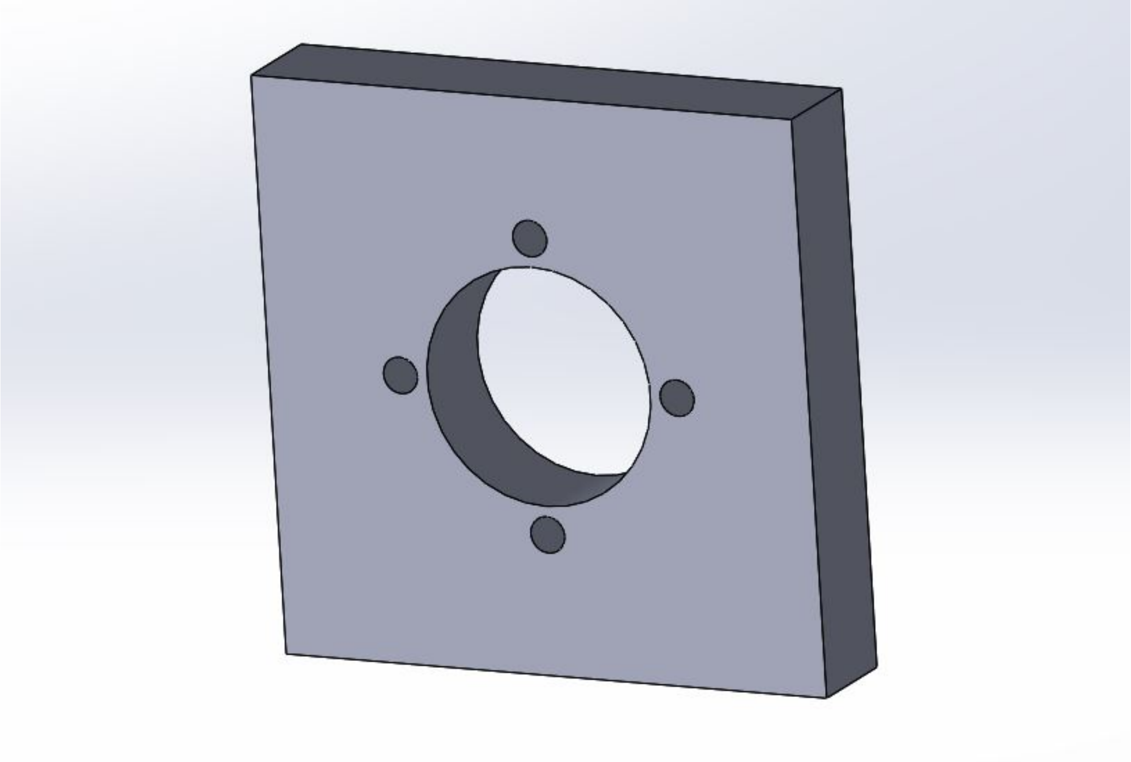


Figure 30: Motor Mount

The MyRIO cover, as shown in Figure 31, was manufactured using ABS plastic on a rapid prototyping 3D plastic printer. The MyRIO cover is used to protect the MyRIO from being damaged while driving the robot. The MyRIO cover bolts onto the baseplate using 0.5in long ¼ - 20 socket head screws. One (1) MyRIO cover was manufactured, and the manufacturing drawing is shown in Appendix A.

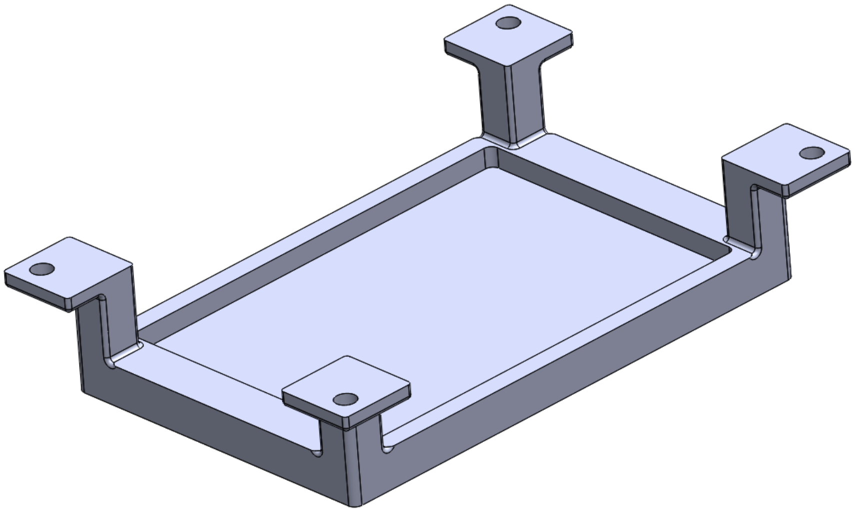


Figure 31: myRIO Cover

The top cover, as shown in Figure 32, was manufactured using ABS plastic on a rapid prototyping 3D plastic printer. The top cover is used to protect the power amplifiers, IMU, and motors from being damaged while driving the “name_bot”. The top cover is attached to the baseplate using Velcro to allow for easy removal and attachment. One (1) top cover was manufactured, and the manufacturing drawing is shown in Appendix A.

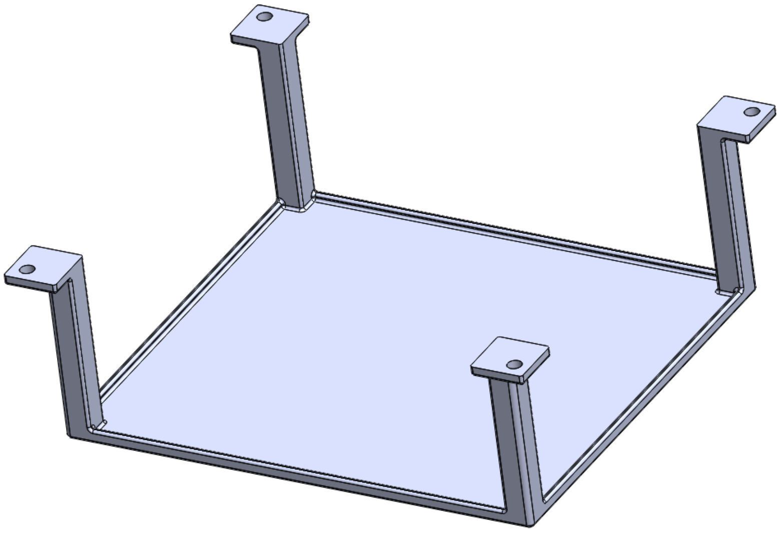


Figure 32: Top Cover

The 8in plastic wheel, as shown in Figure 33, is an 8in plastic wheel purchased from AndyMark.com. The 8in plastic wheel is attached to the drive shaft using six (6) 1.75in long 8-32 Phillips flat head countersink machine screws with 8-32 hex nuts as discussed earlier. Two (2) 8in plastic wheels were used.

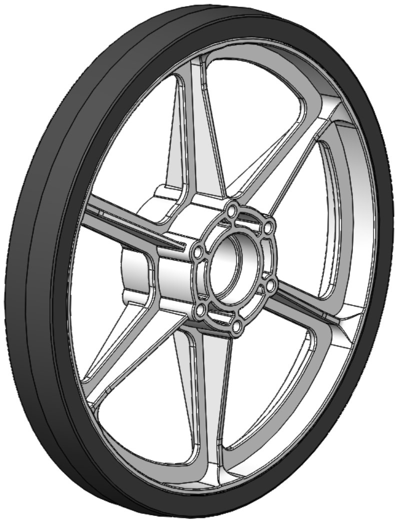


Figure 33: 8 in Plastic Wheel

Figure 34 shows the skateboard bearing used for this project. A total of (4) bearings were used in the drive shaft assembly, (2) bearing per wheel. The bearings are seated inside of the bearing housings and allow for the drive shaft to rotate on axis with limited friction. These bearings were selected because of their low cost and ability to withstand the load of the overall assembly.

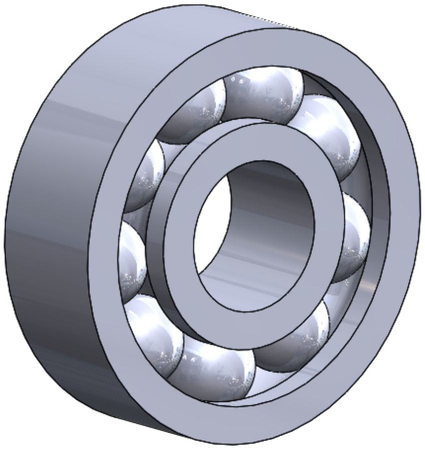


Figure 34: Skateboard Ball Bearing

Figure 35 shows the safety wheels used for this project[3]. A total of two safety wheels were used to limit the damages done to the traveller in the event of lack of balance. These were chosen because of their ability to effectively limit that impact without significantly altering the balance of the traveller. Each safety wheel was affixed to the chassis using two (2) steel ¼”-28 x 1” and matching steel hex nuts.

[3] *v.2* James: Updated to reflect addition of safety wheels for testing before self balancing could be implemented in software.

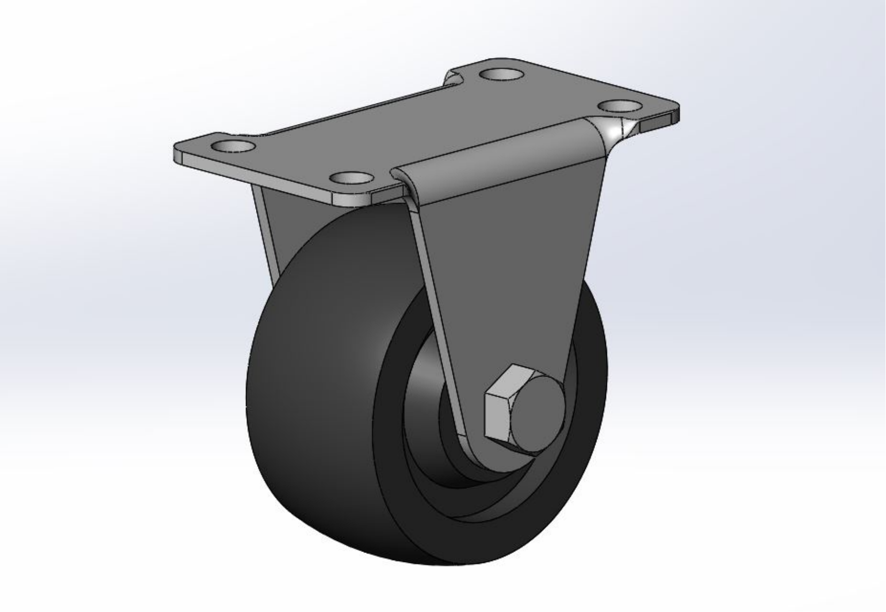


Figure 35: Safety Wheel

Drive Control Design (John Borek, Mitesh Shetty, Arjun Yeravdekar)

Two-Wheeled Cart Model

$$v_1 = r_{wh}\dot{\phi}_1, \qquad v_2 = r_{wh}\dot{\phi}_2,$$

$$v_{car} = \frac{1}{2}(v_1 + v_2) = \frac{1}{2}r_{wh}(\dot{\phi}_1 + \dot{\phi}_2),$$

$$\dot{\psi} = \frac{2}{w}(v_2 - v_1) = \frac{r_{wh}}{w}(\dot{\phi}_2 - \dot{\phi}_1)$$

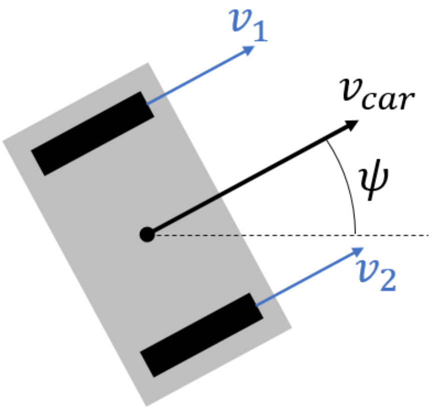


Figure 35: Two-Wheeled Cart

Control Strategy

Desired Wheel Velocities:

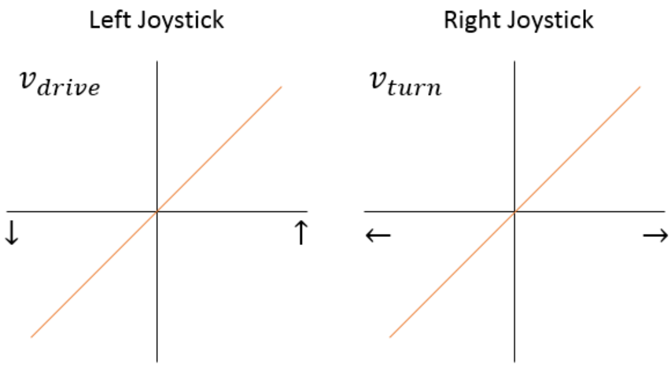


Figure 36: Joystick Mapping

$$v_{1,des} = v_{drive} + v_{turn}, \qquad v_{2,des} = v_{drive} - v_{turn}$$

$$Such\ that: \quad |v_{1,des}|\ and\ |v_{2,des}| \leq v_{max}$$

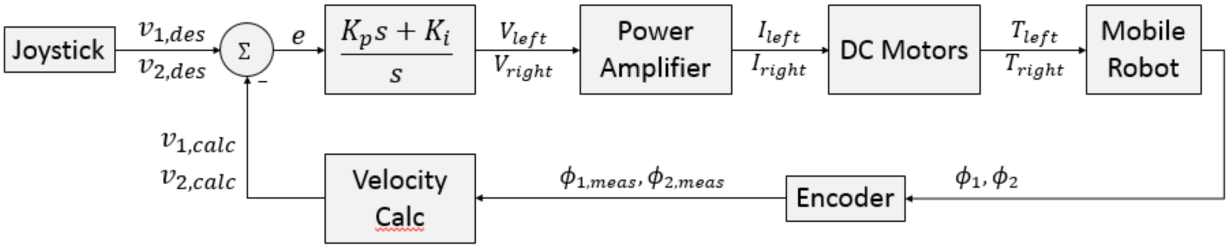


Figure 37: Drive Block Diagram

Where,

- $v_{1,des}, v_{2,des}$ →Desired velocity for wheel 1 and 2
- V_{left}, V_{right} →Voltage input to power amplifier for wheel 1 and 2
- I_{left}, I_{right} →Current input to DC motors for wheel 1 and 2
- T_{left}, T_{right} →Torque applied by wheel 1 and 2
- ϕ_1, ϕ_2 →Actual angular position of wheel 1 and 2
- $□_{1,meas}, □_{2,meas}$ →Measured angular position of wheel 1 and 2

Balance Control Design

Inverted Pendulum Model (John Borek)[4]

$$J_{wh} = \frac{1}{2}mr^2, \qquad J_b = Ml^2$$

$$v_{wh} = \frac{1}{2}r\dot{\phi}, \qquad v_b = \sqrt{v_{b,x}^2 + v_{b,z}^2} \rightarrow v_{b,x} = v_{wh} - l\dot{\theta}\ cos\ cos\ \theta\ , \qquad v_{b,z} = -l\dot{\theta}\ sin\ sin\ \theta$$

$$L = KE_R + KE_T - PE$$

[4] *v.2* Not implemented.

$$KE_R = \frac{1}{2}J_{wh}\dot{\phi}^2 + \frac{1}{2}J_b\dot{\theta}^2, \qquad KE_T = \frac{1}{2}mv_{wh}^2 + \frac{1}{2}Mv_b^2, \qquad PE = Mgl\, cos\, cos\, \theta$$

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{\phi}} - \frac{\partial L}{\partial \phi} = T_{wh}, \qquad \frac{d}{dt}\frac{\partial L}{\partial \dot{\theta}} - \frac{\partial L}{\partial \theta} = 0$$

Non-Linear Equations of Motion:

$$\ddot{\phi} = \frac{8T_{wh} + gmr\, sin\, sin\, (2\theta)\ - 4lMr\, sin\, sin\, (\theta)\, \dot{\theta}^2}{r^2(6m + 2M - M(\theta)\ )}$$

$$\ddot{\theta} = \frac{-2T_{wh}\, cos\, cos\, (\theta)\ - gm(3m + M)r\, sin\, sin\, (\theta)\ + lM^2r\, cos\, cos\, (\theta)\ sin\, sin\, (\theta)\, \dot{\theta}^2}{lMr(-2(3m + M) + M(\theta)\ )}$$

Linearized Equations of Motion:

$$[\dot{x}_1\ \dot{x}_2\ \dot{x}_3\ \dot{x}_4\ ] = [0\ 1\ 0\ 0\ 0\ 0\ A_{23}\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ A_{43}\ 0\ ][x_1\ x_2\ x_3\ x_4\ ] + [0\ B_{21}\ 0\ B_{41}\ ]u,$$
$$where\ x = [\phi\ \dot{\phi}\ \theta\ \dot{\theta}\ ]^T,$$

$and\ A_{23} = \frac{2gm}{(6m+M)r},\ A_{43} = \frac{gm(3m+M)}{lM(6m+M)},$

$$B_{21} = \frac{8}{(6m + M)r^2}, \qquad B_{41} = \frac{2}{6lmr + lMr}$$

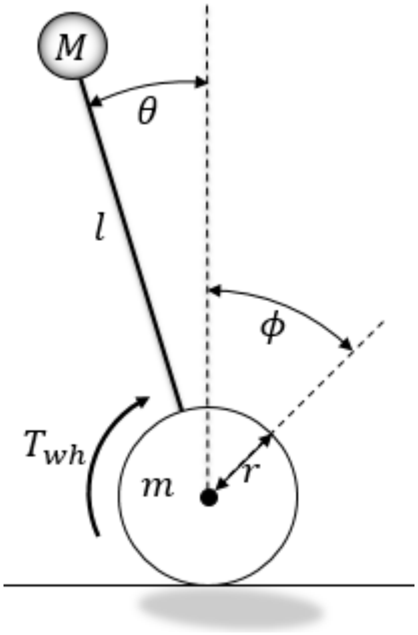


Figure 38: Planar Wheeled Inverted Pendulum

Control Strategy

State Feedback control on $\dot{\phi}, \theta, and\ \dot{\theta}$ to maintain upright configuration. Control gains are selected to maintain negative eigenvalues for the linearized state matrix.

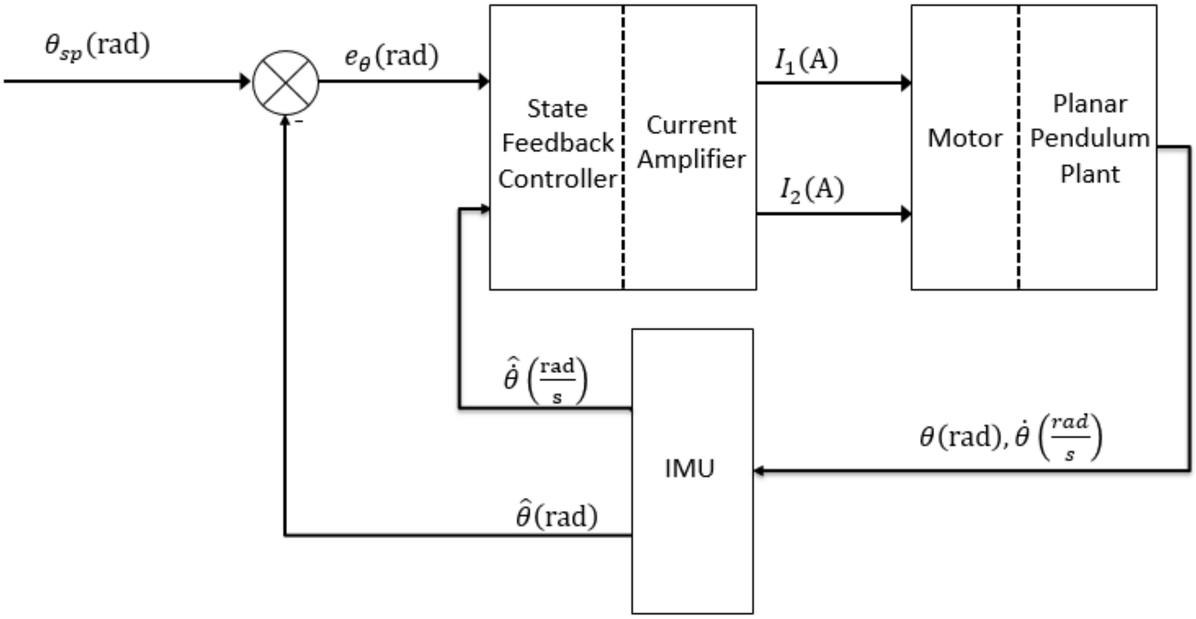
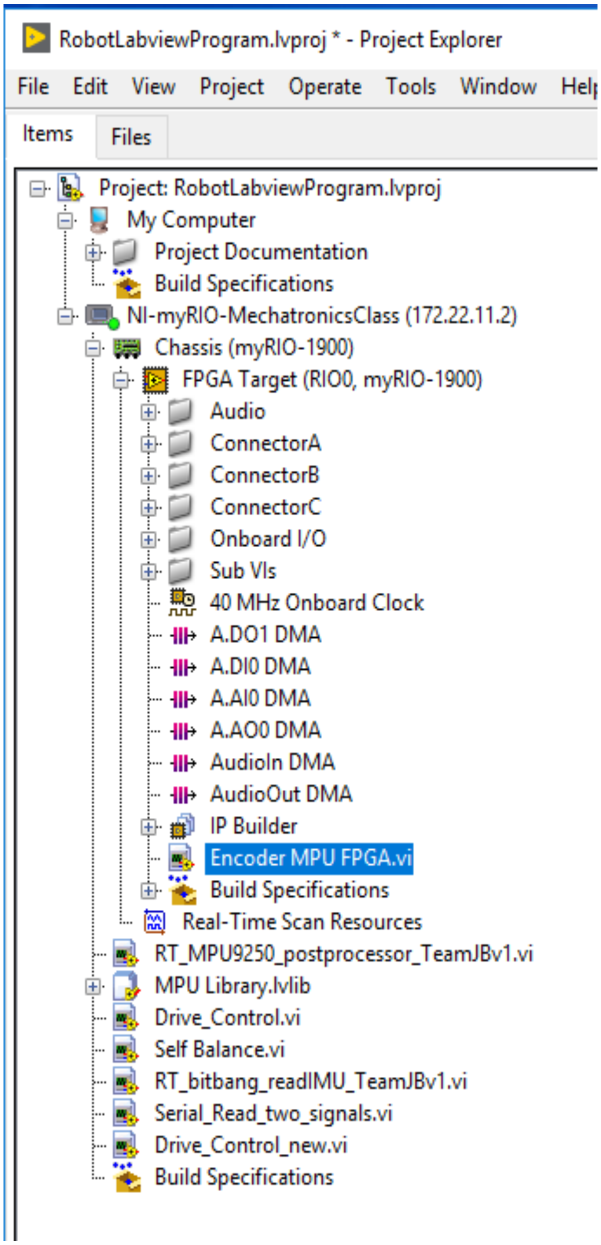

θ_{sp}(rad)
-
e_θ(rad)
State Feedback Controller
Current Amplifier
I_1(A)
I_2(A)
Motor
Planar Pendulum Plant
$\hat{\dot{\theta}}\left(\frac{\text{rad}}{\text{s}}\right)$
θ(rad), $\dot{\theta}\left(\frac{rad}{s}\right)$
IMU
$\hat{\theta}$(rad)

Figure 39: Inverted Pendulum Control Block Diagram

Program Code List (Chunjie and Jasmine)[5]



RobotLabviewProgram.lvproj * - Project Explorer
File Edit View Project Operate Tools Window Hel
Items Files

```
Project: RobotLabviewProgram.lvproj
    My Computer
        Project Documentation
        Build Specifications
    NI-myRIO-MechatronicsClass (172.22.11.2)
        Chassis (myRIO-1900)
            FPGA Target (RIO0, myRIO-1900)
                Audio
                ConnectorA
                ConnectorB
                ConnectorC
                Onboard I/O
                Sub VIs
                40 MHz Onboard Clock
                A.DO1 DMA
                A.DI0 DMA
                A.AI0 DMA
                A.AO0 DMA
                AudioIn DMA
                AudioOut DMA
                IP Builder
                Encoder MPU FPGA.vi
                Build Specifications
            Real-Time Scan Resources
        RT_MPU9250_postprocessor_TeamJBv1.vi
        MPU Library.lvlib
        Drive_Control.vi
        Self Balance.vi
        RT_bitbang_readIMU_TeamJBv1.vi
        Serial_Read_two_signals.vi
        Drive_Control_new.vi
        Build Specifications
```

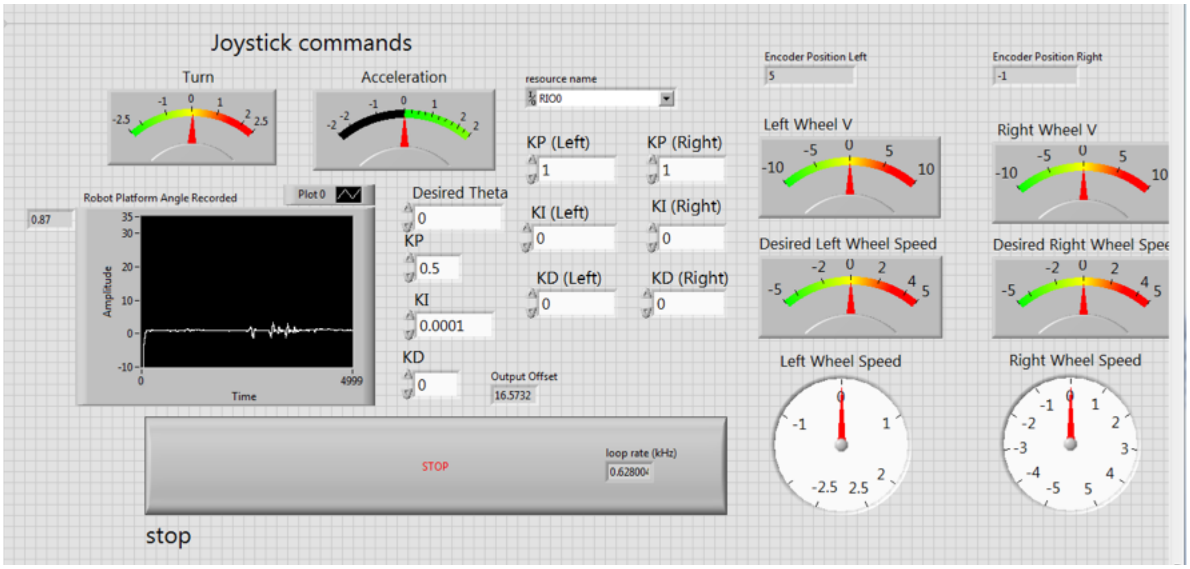
Figure 40: Project Description Tree

This is the project description tree and below are the detailed programs used.

[5] *v.2* Alex: Updated list and descriptions to reflect current status.

Drive Control

This program is used to drive the robot around in a stable configuration. In *v.2*, speed calculation has been fixed, however the I term of the PID speed controllers has been removed. Self balancing has also been implemented to help control the robot while driving. When acceleration is zero, the robot is set to go to an angle of 0°. When acceleration is increased in either direction, the robot is set to tilt to 20° in that direction to prevent it from slamming into the ground and to maintain a stable platform.



resource name: RIO0

Encoder Position Left: 5

Encoder Position Right: -1

Desired Theta: 0

KP: 0.5

KI: 0.0001

KD: 0

KP (Left): 1

KP (Right): 1

KI (Left): 0

KI (Right): 0

KD (Left): 0

KD (Right): 0

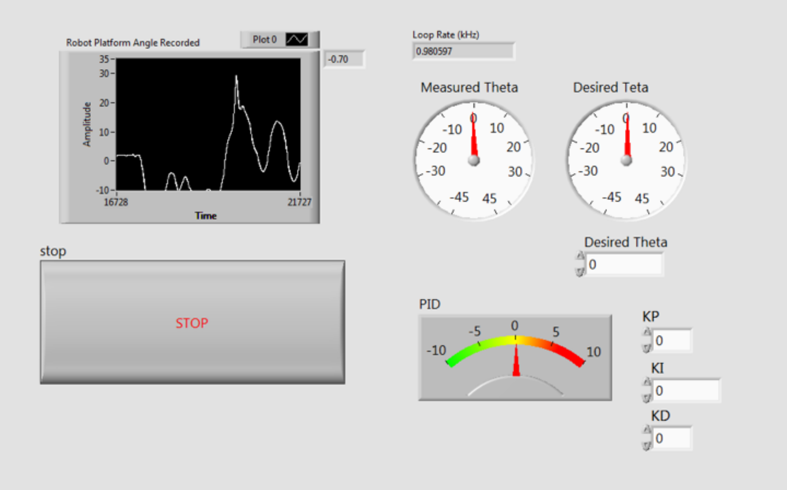
Output Offset: 16.5732

loop rate (kHz): 0.62800(

Figure 41: LabView Drive Control

Self-Balance

This program is used for balancing the robot in an unstable configuration. In *v.2*, the robot can successfully tilt to and maintain a desired angle.



Loop Rate (kHz): 0.980597

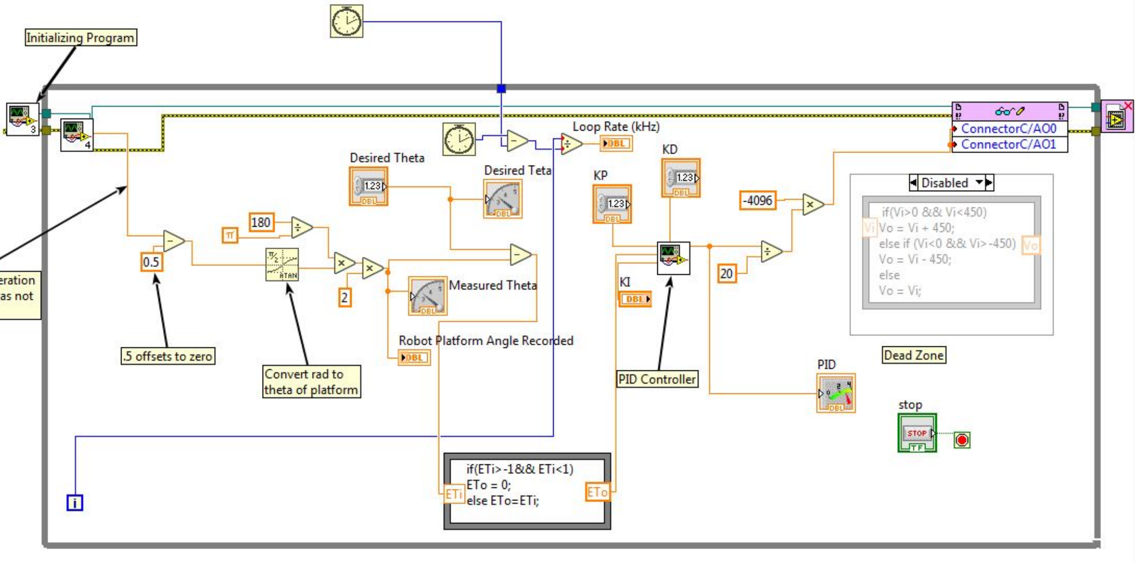
Desired Theta: 0

KP: 0

KI: 0

KD: 0

Figure 42: LabView Self-Balance



Initializing Program

Theta is found through x acceleration only currently, z acceleration was not useful. (may not be needed)

.5 offsets to zero

Convert rad to theta of platform

PID Controller

Dead Zone

```
if(ETi>-1&& ETi<1)
ETo = 0;
else ETo=ETi;
```

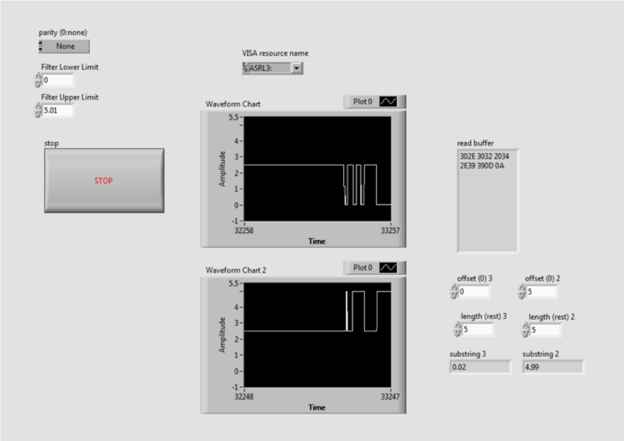
```
if(Vi>0 && Vi<450)
Vo = Vi + 450;
else if (Vi<0 && Vi>-450)
Vo = Vi - 450;
else
Vo = Vi;
```

Figure 43: Self-Balancing Code

Self-balancing the robot is controlled by the above figure. It first initializes the IMU using the bitbang code. After initializing, those initializing numbers are sent to a program that reads and displays the current acceleration of the robot in x,y,z coordinates measured in g's. The x acceleration is read and converted from radians to degrees and sent to a PID controller. The actual angle is measured and compared to the desired angle. If it exceed the max desired angle tolerance (positive or negative) the robot slows down or reverses direction. The code has been tested in lab and does work properly in measuring the angle of the chassis but robot has not been physically tested using the code and will most likely need some tuning.

XBee Read[6]

This program was used for wireless controls. It has an outlier cancellation algorithm to eliminate the corrupted data that was occasionally sent from the XBee.



parity (0:none): None

VISA resource name: ASRL3:

Filter Lower Limit: 0

Filter Upper Limit: 5.01

read buffer: 302E 3032 2034 2E39 390D 0A

offset (0) 3: 0

offset (0) 2: 5

length (rest) 3: 5

length (rest) 2: 5

substring 3: 0.02

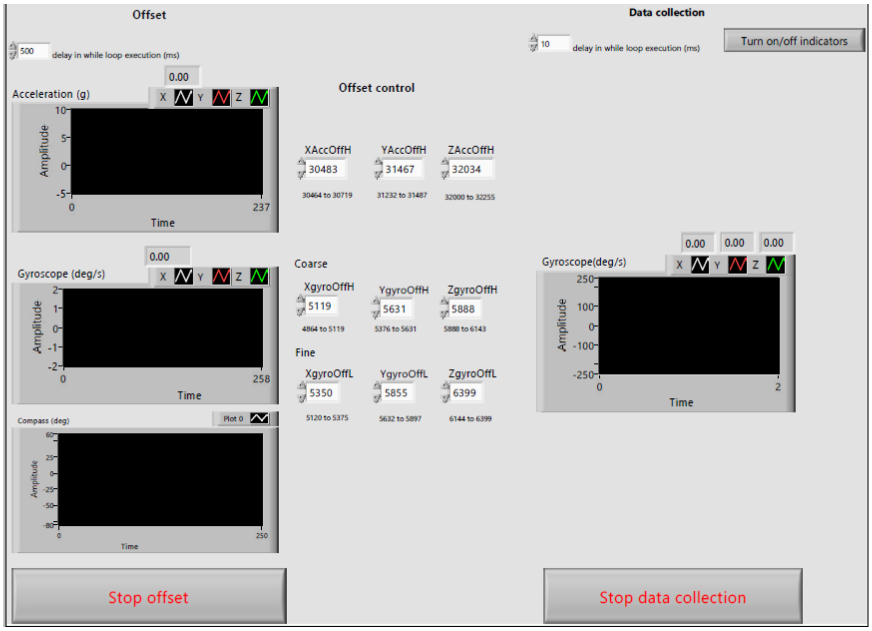
substring 2: 4.99

Figure 44: Wireless control program

[6] *v.2* Omar & Larry: Updated to reflect improved program.

Read IMU

This is the main program that calls IMU variables from the FPGA and conditions them to use for balancing controls.



Offset

500 delay in while loop execution (ms)

Offset control

XAccOffH 30483 (30464 to 30719)

YAccOffH 31467 (31232 to 31487)

ZAccOffH 32034 (32000 to 32255)

Coarse

XgyroOffH 5119 (4864 to 5119)

YgyroOffH 5631 (5376 to 5631)

ZgyroOffH 5888 (5888 to 6143)

Fine

XgyroOffL 5350 (5120 to 5375)

YgyroOffL 5855 (5632 to 5897)

ZgyroOffL 6399 (6144 to 6399)

Data collection

10 delay in while loop execution (ms)

Figure 45: Main program

System Block Diagram (John Borek)

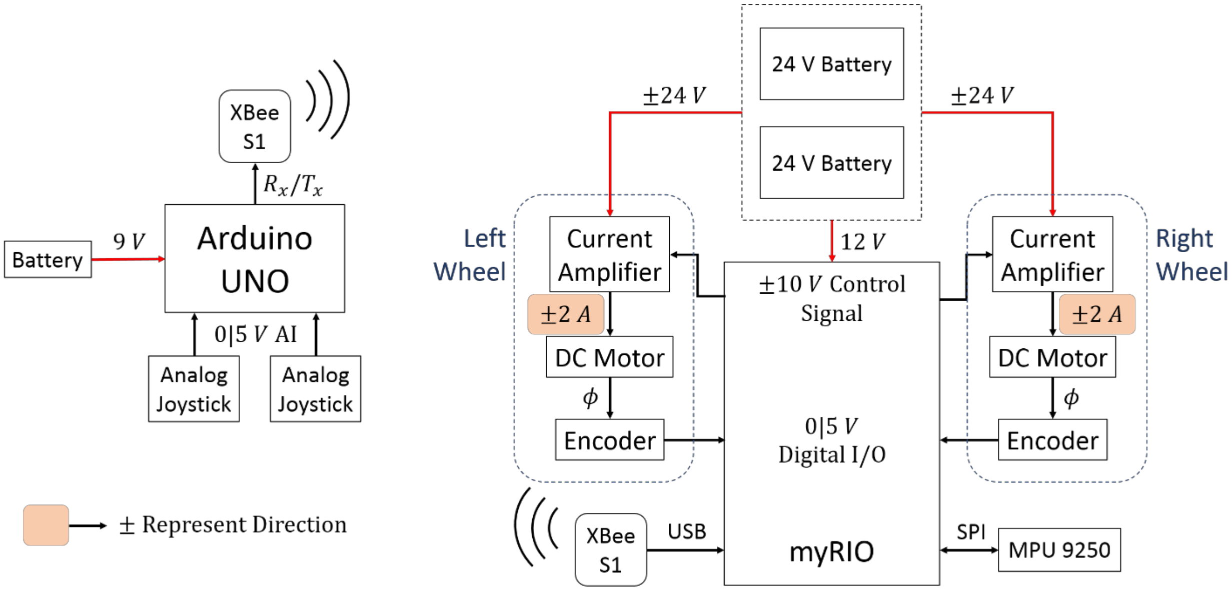


Figure 46: System Block Diagram

An Arduino Uno, powered by a 9 V portable battery, reads the analog signal from two individual joysticks. After reading each joystick's position, the Arduino transmits the information to the myRIO via an XBee radio module, wired to its Rx/Tx pins. The receiving XBee is connected to the myRIO through an XBee explorer, directly wired to the myRIO's USB port.

The myRIO is powered by a 12 V connection off a 24 V rechargeable battery. Two of these batteries are wired in series to produce a 48 V differential to the current amplifiers to drive the motors in two directions. The current amplifiers are also connected to the myRIO to receive an analog control signal, from -10 to +10 V, that dictates the amount and direction of current to send to the DC motors. An encoder on each wheel measures their angular position and sends that information to the myRIO via a digital signal.

Finally, an inertial measurement unit (IMU) is connected to the myRIO to provide orientation information about the robot. The IMU and myRIO communicate through an SPI serial protocol.

Implementation (Ben Groelke)[7]

The name_bot is a self-balancing robot which can also be driven through wireless control. Drive and balance controls are uploaded to the myRIO processor, the wireless user input is handled by the Arduino and transmitted/received by two Xbee s1 for a range up to 30ft indoors and 60ft outdoors. Two 24 batteries power the myRIO and motors for up to 3.5hrs with average driving. After installation is complete, get started by following the instructions below

1. Turn batteries off and charge batteries until they are fully powered

[7] *v.2* Justin: Updated to reflect new procedures required with updated programs.

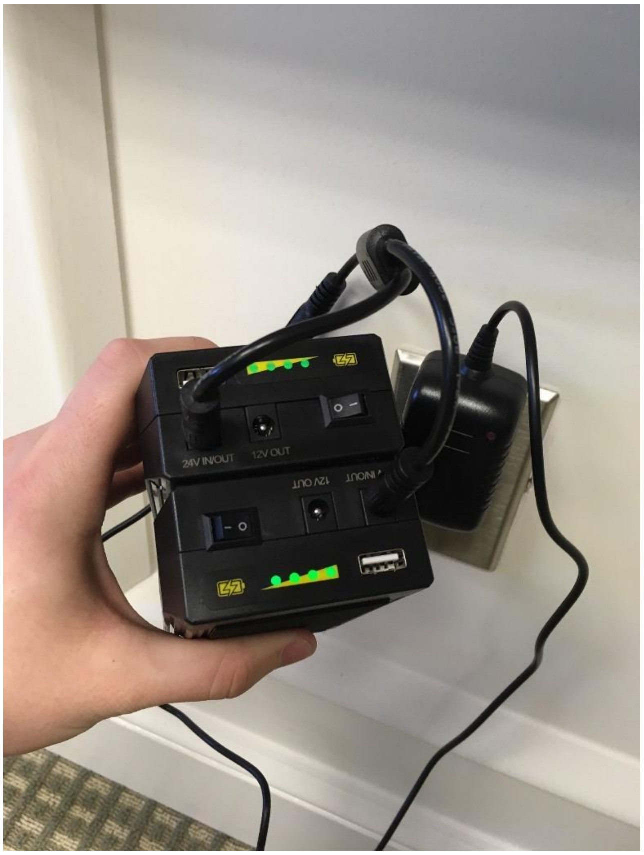


Figure 47: Batteries Powered on and Fully Charged

Batteries will be fully powered when all 4 LEDs are lit.

2. Disconnect batteries from charger and keep switch turned off. Secure batteries to robot as shown using the Velcro pads.

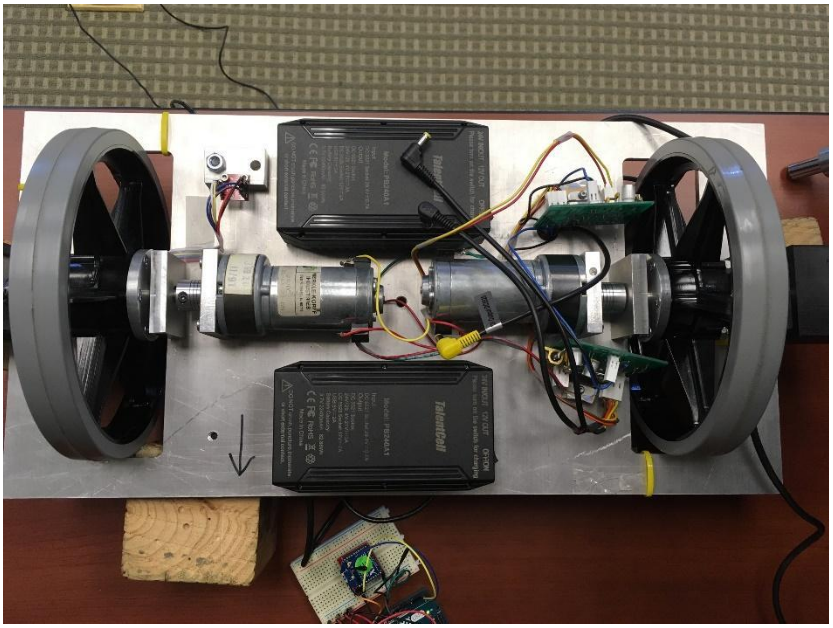


Figure 48: Top View of Robot

3. While batteries remain turned off, plug in the two black power plugs into either 24 V ports on each battery.

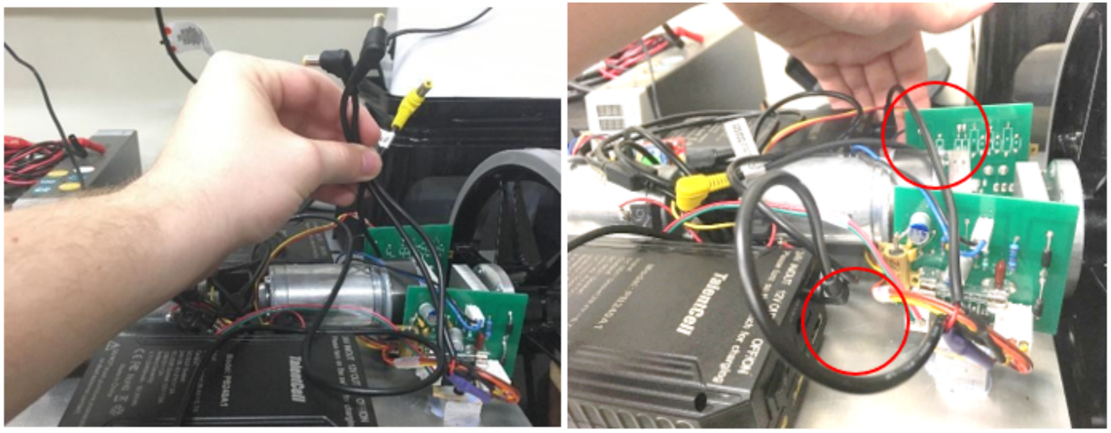


Figure 49: Black and Yellow Power Plugs for Batteries

4. Plug in the yellow power plug into a 12 V port on either battery. The cable with the yellow power plugs is two-sided, plug in the other side into the myRIO.

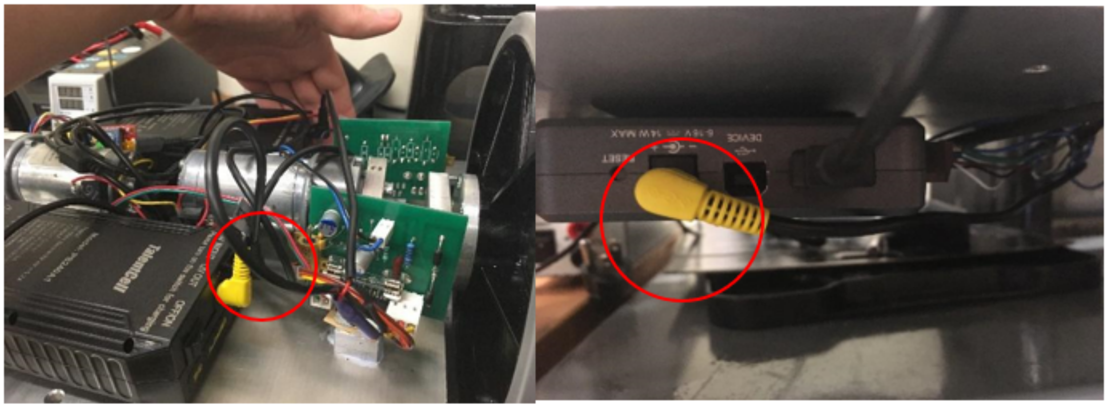


Figure 50: Plugs for myRIO and Batteries

5. Turn batteries on, myRIO light should come on. Plug in myRIO to computer via USB-A. A LabVIEW pop-up should appear, select "Do Nothing".

6. Open up RobotLabviewProgram.lvproj in LabVIEW. Right click on the myRIO and select "connect".

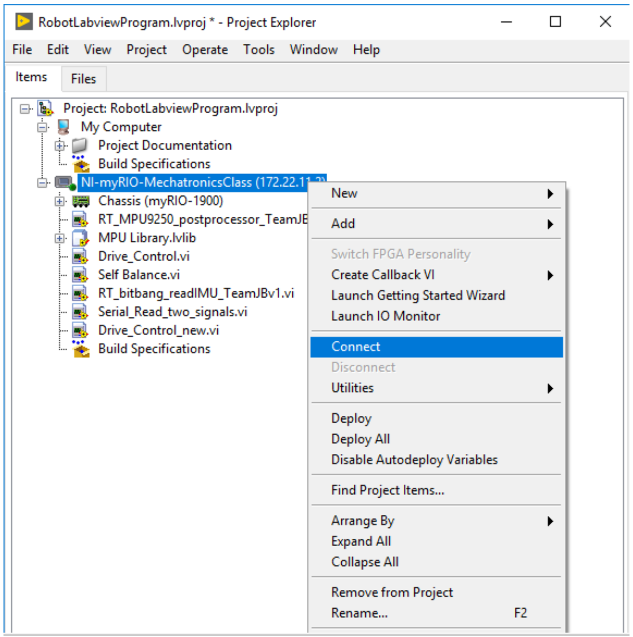
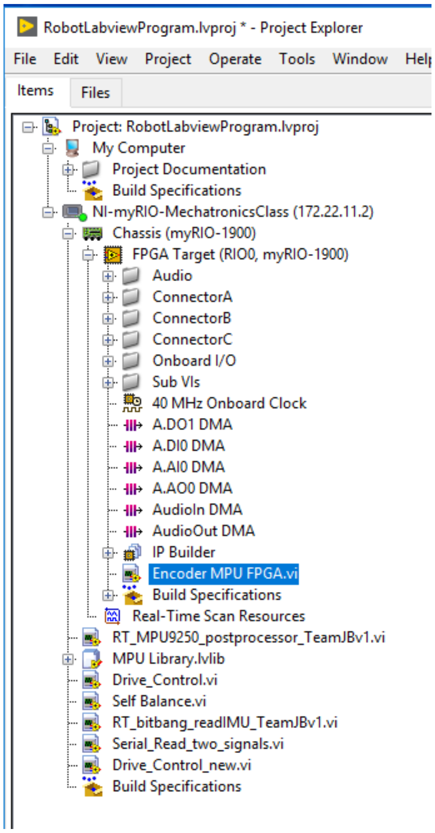


Figure 51: Connecting myRIO

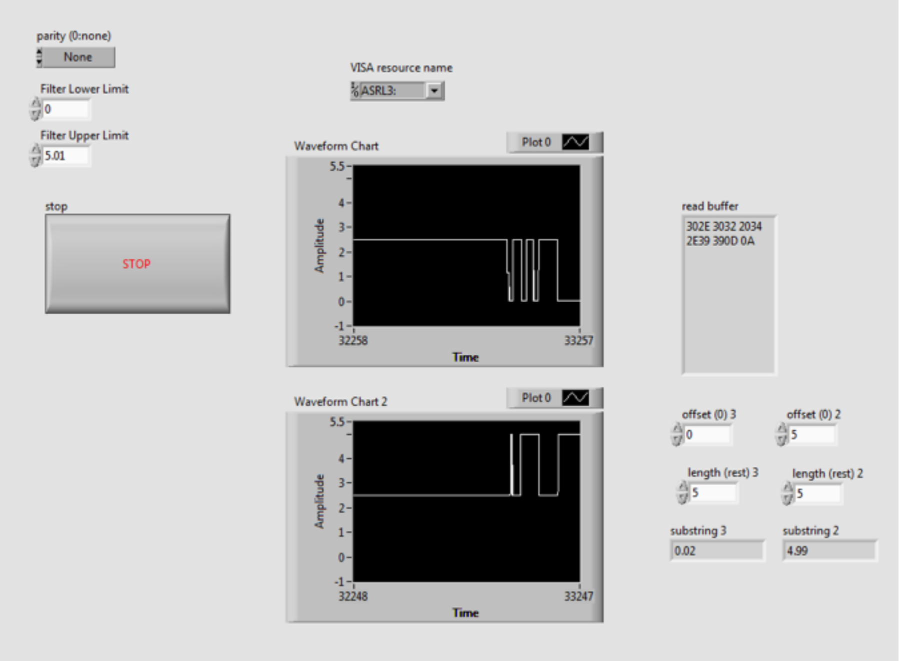
7. Open "Drive Control.vi" and see if it is broken. If "Drive Control.vi" is broken you need to close "Drive Control.vi" and compile "Encoder MPU FPGA.vi" on the FPGA. Then close "Drive Control.vi".



```
Project: RobotLabviewProgram.lvproj
  My Computer
    Project Documentation
    Build Specifications
  NI-myRIO-MechatronicsClass (172.22.11.2)
    Chassis (myRIO-1900)
      FPGA Target (RIO0, myRIO-1900)
        Audio
        ConnectorA
        ConnectorB
        ConnectorC
        Onboard I/O
        Sub VIs
        40 MHz Onboard Clock
        A.DO1 DMA
        A.DI0 DMA
        A.AI0 DMA
        A.AO0 DMA
        AudioIn DMA
        AudioOut DMA
        IP Builder
        Encoder MPU FPGA.vi
        Build Specifications
      Real-Time Scan Resources
    RT_MPU9250_postprocessor_TeamJBv1.vi
    MPU Library.lvlib
    Drive_Control.vi
    Self Balance.vi
    RT_bitbang_readIMU_TeamJBv1.vi
    Serial_Read_two_signals.vi
    Drive_Control_new.vi
    Build Specifications
```

Figure 52: Encoder MPU FPGA

8. Once you are positive that “Encoder MPU FPGA.vi” is compiled open “XBee Read.vi”. Enter “5.01” for the value of “Filter Upper Limit”. The front panel graphs should read the both joystick values at around 2.5V for no user input.



parity (0:none): None

Filter Lower Limit: 0

Filter Upper Limit: 5.01

stop

VISA resource name: ASRL3:

read buffer: 302E 3032 2034 2E39 390D 0A

offset (0) 3: 0

offset (0) 2: 5

length (rest) 3: 5

length (rest) 2: 5

substring 3: 0.02

substring 2: 4.99

Figure 53: Waveform Chart

9. Supply power to Arduino. Once the Joysticks are working properly as described in step 8, close out “XBee Read.vi” and open “Drive Control.vi” and run.

Note: If you want to recompile the joystick arduino sketch, open “Controller_analog_read.ino” and upload.

10. Once the program has finished running, you can unplug the USB-A cord from the myRIO and the name_robot is ready to drive.

Test Document

There were three major systems that were tested developing this robot, the drive system, the instrumentation, and the robot’s controls.

Drive System

Batteries/Power Amplifiers/Motors (Chunjie Fan and Kristen Venditti)

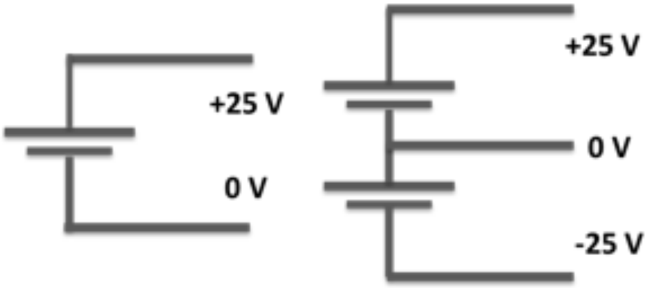
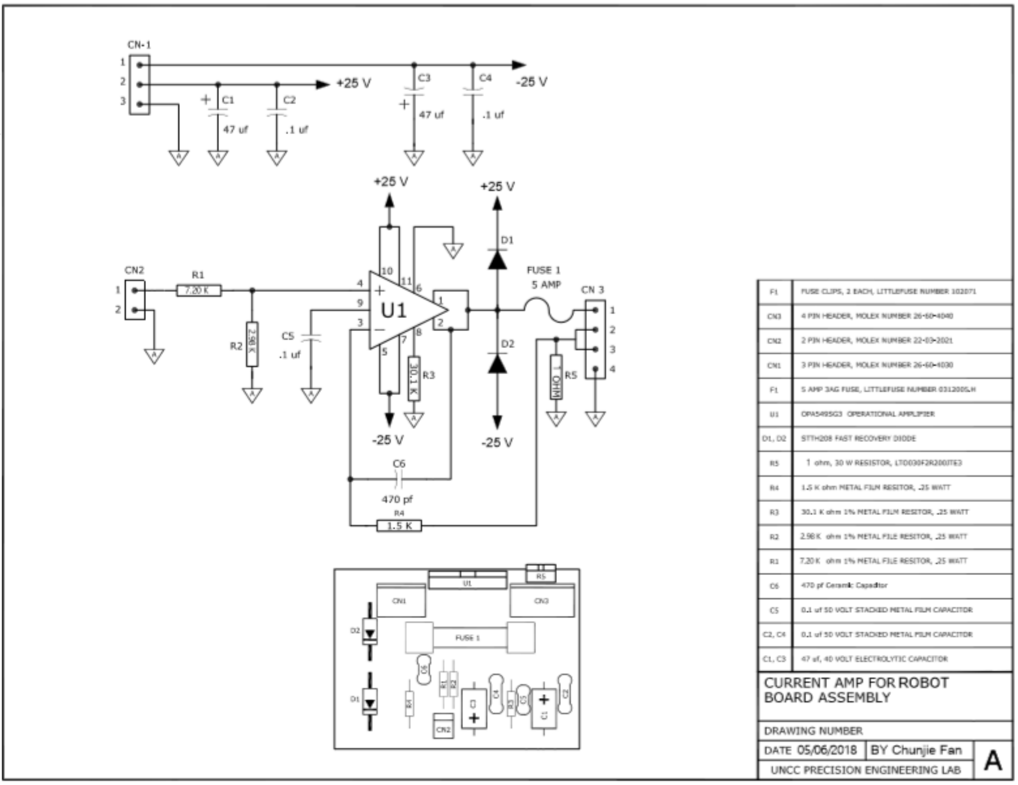


Figure 54: Unipolar battery and Batteries connected in Series

There are two unipolar 25 V batteries. When they are connected in series, they become a 50 V potential difference battery. The new battery will become a bipolar power source, which has ±25 V power source that will be connected to the power amplifiers, which are then connected to the motors.



F1	FUSE CLIPS, 2 EACH, LITTLEFUSE NUMBER 102071
CN3	4 PIN HEADER, MOLEX NUMBER 26-60-4040
CN2	2 PIN HEADER, MOLEX NUMBER 22-03-2021
CN1	3 PIN HEADER, MOLEX NUMBER 26-60-4030
F1	5 AMP 3AG FUSE, LITTLEFUSE NUMBER 0312005.H
U1	OPA549SG3 OPERATIONAL AMPLIFIER
D1, D2	STTH208 FAST RECOVERY DIODE
R5	1 ohm, 30 W RESISTOR, LTO030F2R200JTE3
R4	1.5 K ohm METAL FILM RESITOR, .25 WATT
R3	30.1 K ohm 1% METAL FILM RESITOR, .25 WATT
R2	2.98 K ohm 1% METAL FILE RESITOR, .25 WATT
R1	7.20 K ohm 1% METAL FILE RESITOR, .25 WATT
C6	470 pf Ceramic Capacitor
C5	0.1 uf 50 VOLT STACKED METAL FILM CAPACITOR
C2, C4	0.1 uf 50 VOLT STACKED METAL FILM CAPACITOR
C1, C3	47 uf, 40 VOLT ELECTROLYTIC CAPACITOR

CURRENT AMP FOR ROBOT
BOARD ASSEMBLY

DRAWING NUMBER

DATE 05/06/2018 BY Chunjie Fan
UNCC PRECISION ENGINEERING LAB A

Figure 55: Power Amplifier Circuit

$$\frac{I_{out}}{V_{in}} = \frac{R_2}{R_5(R_1 + R_2)} = \frac{2980}{1(7200 + 2980)} = 0.2927$$

Equation: Current calculation of Power Amplifier

Based on the circuit of the amplifier, the largest current the amplifier can supply is 2.927 ampere as seen in Equation 1. Based on the test, the largest voltage output from pin 1&2 will be never larger than the value of the power source. In fact, the largest current is 24/12 = 2 ampere.

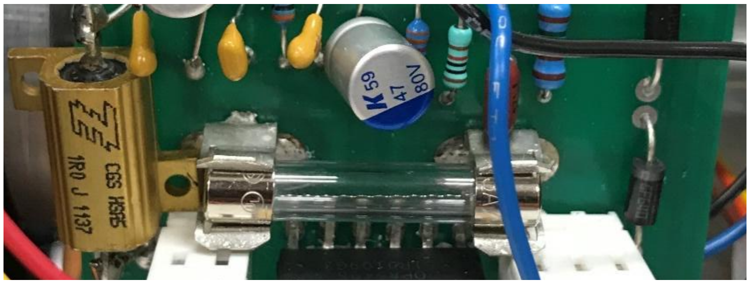


Figure 56: Power Amplifier

There are two 24 V DC motors where each drive a shaft that is connected to the wheels of the robot. There is an unknown resistance from the gear box and the coil inside the motor due to not knowing the gear ratio. The motors are from 1991, so they were taken apart to be cleaned and analyzed for major wear.

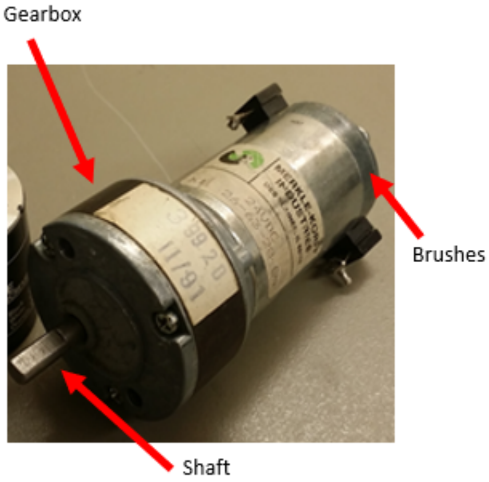


Figure 57: 24 V DC Motor

Motor Characteristics

Since there were no specifications or information online about the 24 V DC motors, they had to be tested to figure out the capabilities and limitations. To figure out the stall torque, a motor was fixed to a plate with a lever on the motor's shaft where a specific current was given to the motor. The lever would press down on a scale and the weight was recorded when the motor would stall. The motor torque was calculated using motor torque equation below to determine the stall torque at different currents, which is shown in Figure 57.

$$Motor\ Torque\ (Nm) = Stall\ force\ (N) * Lever\ arm\ (m)$$

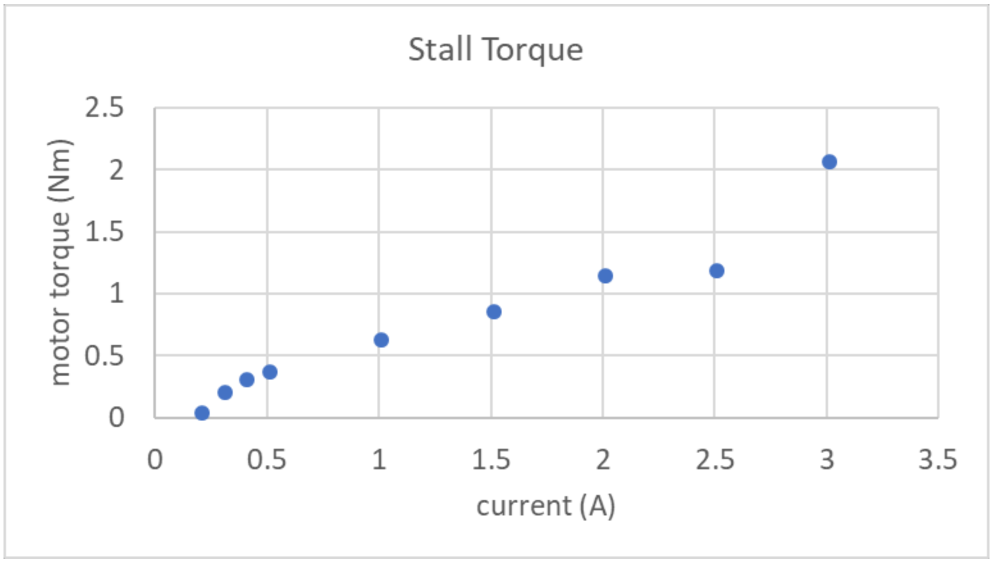


Figure 58: Stall Torque at 24 V

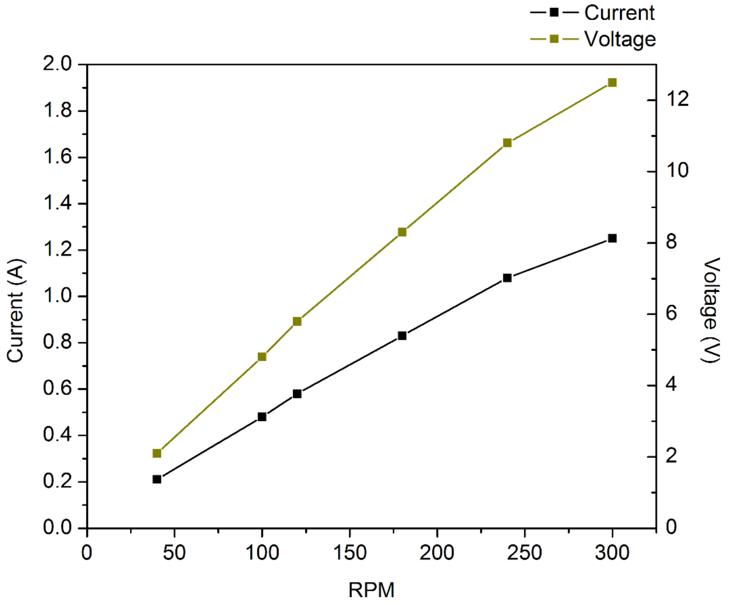


Figure 59: Motor RPM with No-Load

The motor runs between 15 to 300 RPM in a no-load situation. When the speed is within positive and negative 15 RPM, the motor will not run due to the backlash of the gear box and the friction force inside the motor and gear system.

With robot load and shaft friction, the motor runs between 15 to 100 RPM. $V = 100 * 2\pi * 0.1/60 =$ 1.04 m/s.

Instrumentation

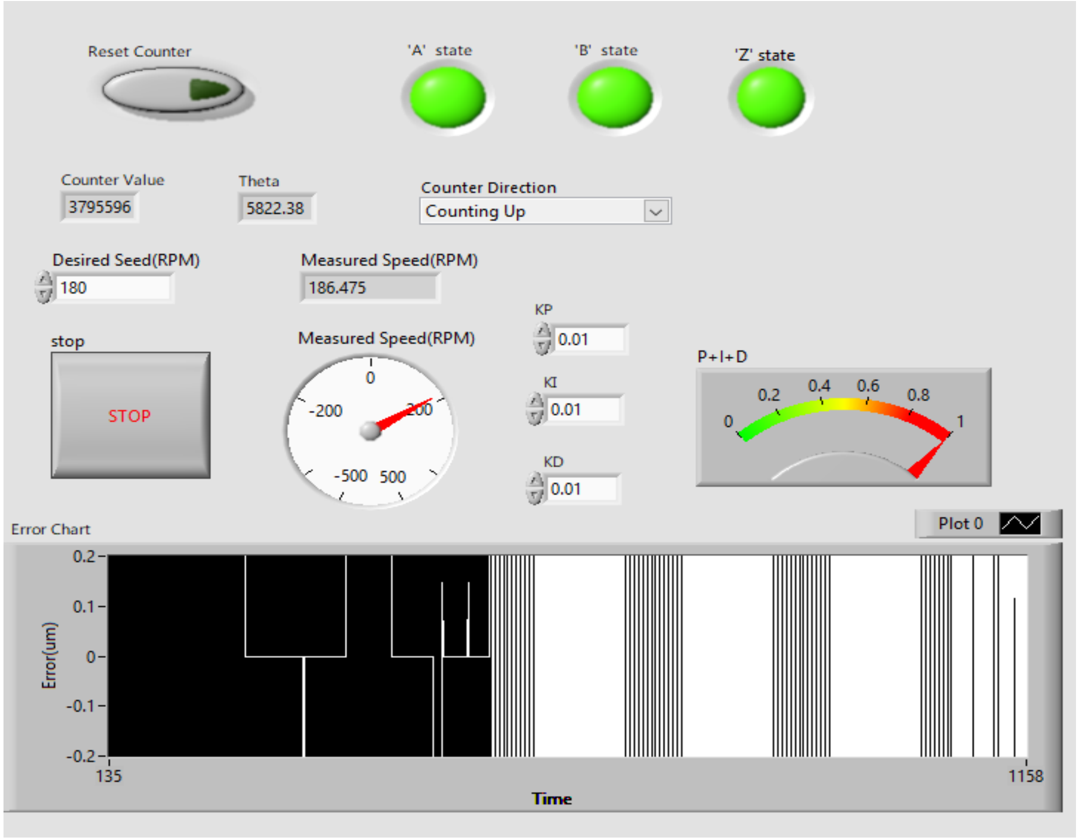
Encoder (Chunjie Fan)

Encoder measurement was compared to optical interrupt sensor. The sensor has a voltage output signal, which varies from 0.1 to 4.7 V based on the light interrupt. When the blade blocks the light from the emitter to the detector, the voltage will be drop down, otherwise, it will keep 4.7 V. The oscilloscope and myRIO are used to detect the frequency of the optical sensor and rotation speed of the encoder. The optical interrupt sensor and the test results are as follows.

Vout

GND

15V



Counter Value 3795596

Theta 5822.38

Counter Direction: Counting Up

Desired Seed(RPM) 180

Measured Speed(RPM) 186.475

KP 0.01

KI 0.01

KD 0.01

Based on the test result of the optical interrupt sensor and the encoder. The test frequency of the optical sensor is 3.03Hz, which is 181.8 RPM. The labview shows the desired speed is 180 RPM, the measured speed is 186.475 RPM. The error is about 6 RPM, which is because the encoder is not fixed.

IMU: MPU-9250 (Shamir Bin-Karim)

The MPU-9250 IMU breakout board from Sparkfun is based on a MPU-9250 chip, which is a multi-chip module (MCM) made by InvenSense. It has a 3-Axis gyroscope and a 3-Axis accelerometer and an AK8963 3-Axis magnetometer. Altogether, the MPU-9250 is a 9-axis motion tracking device. It also has a Digital Motion Processor™ (DMP). Its dimension is 3x3x1mm.

Specs:

Gyroscope: Triple-axis MicroElectroMechanical Systems (MEMS) gyroscope

- A user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps), integrated 16-bit ADCs
- Digitally programmable low-pass Gyroscope filter
- Gyroscope operating current: 3.2mA

Magnetometer: AK8963 Triple-axis MEMS magnetometer

- A magnetometer full-scale range of ±4800µT, integrated 16-bit ADCs
- Magnetometer normal operating current: 280µA at 8Hz repetition rate

Accelerometer: Triple-axis MEMS accelerometer

- A user-programmable digital-output triple-axis accelerometer, full-scale range of ±2g, ±4g, ±8g and ±16g and integrated 16-bit ADCs
- Accelerometer normal operating current: 450µA

General:

- VDD supply voltage range of 2.4 – 3.6V
- Communication: I2C up to 400kHz or SPI up to 1MHz

For more IMU specs, visit:

https://www.sparkfun.com/products/13762

The IMU-9250 breakout board from Sparkfun uses I2C for communication, but we have used SPI protocol. To convert the Sparkfun breakout board, ADO/SDO is soldered to ground, to SPI compatible, the SJ2 jumper is needed to be desoldered and resoldered according to the following picture:

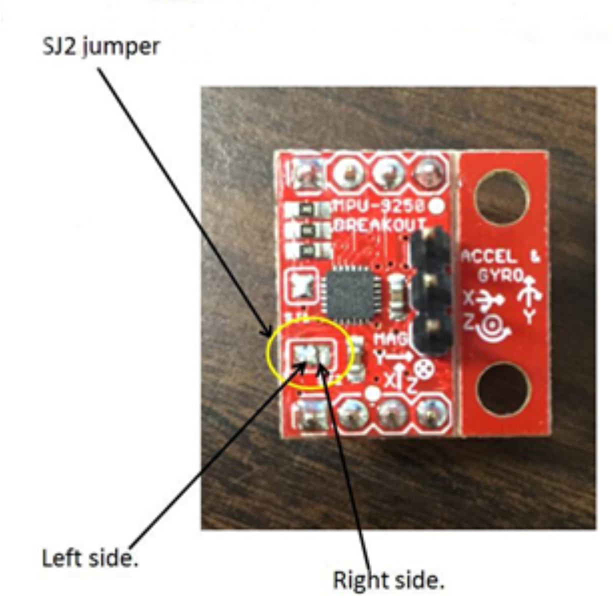


Figure 60: Configuring IMU from I2C to SPI compatible

How to assess and test the IMU:

The IMU data has been accessed using MyRIO fpga. For connecting the IMU with MyRIO, use the wiring diagram discussed in 'Wiring of components'. If you have an IMU that uses I2C protocol, you may use that directly. This document has an Appendix where we will discuss about using I2C protocol. But our default choice is SPI.

Joystick

1. Plug joystick/Arduino into computer.
2. Open Arduino IDE serial plotter to view joystick inputs

XBee

1. Insert each XBee into explorer and plug them into computer.
2. Open XCTU and "find" each XBee.
3. Open each XBee in separate windows.
4. Select the terminal tab in top right corner.
5. Type messages to each other to test calibration.

Troubleshooting (Ben Groelke, Chunjie Fan)

"Even though I only am inputting a forward drive command, the robot is turning" or "Robot is too responsive/too slow". Tune the PID parameters for each wheel in "Drive Control.vi".

Robot will not Power

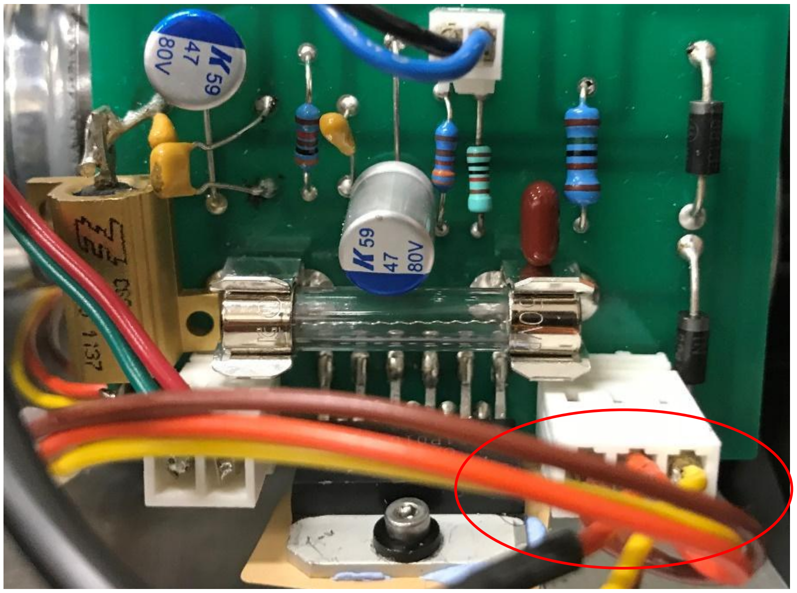
"Battery isn't powering system, even though it was just fully charged"

Solution 1

This can happen when the power plugs (see getting started steps 3 and 4) are plugged in to the battery while the batteries are turned on, instead of off. Doing this can immediately cause the batteries to temporarily power off. To fix this simply take off the batteries and plug them into the wall charger for a moment, this should fix the issue.

Solution 2

Step 1. Verify incoming voltage to robot is present (±25 VDC), red color wire is positive, brown color wire is zero and yellow color wire is negative. If voltage is present, proceed to Step 2. Otherwise, correct incoming line power to robot.



Step 2. Inspect fuse board wiring and ensure all plugs are securely fastened to board.

Step 3. Verify that fuses are not open. Check incoming voltage at bottom of both fuses and outgoing voltage at top of both fuses, if no voltage is present at the top of both fuses, remove fuses from the fuse holders and measure continuity across each fuse.

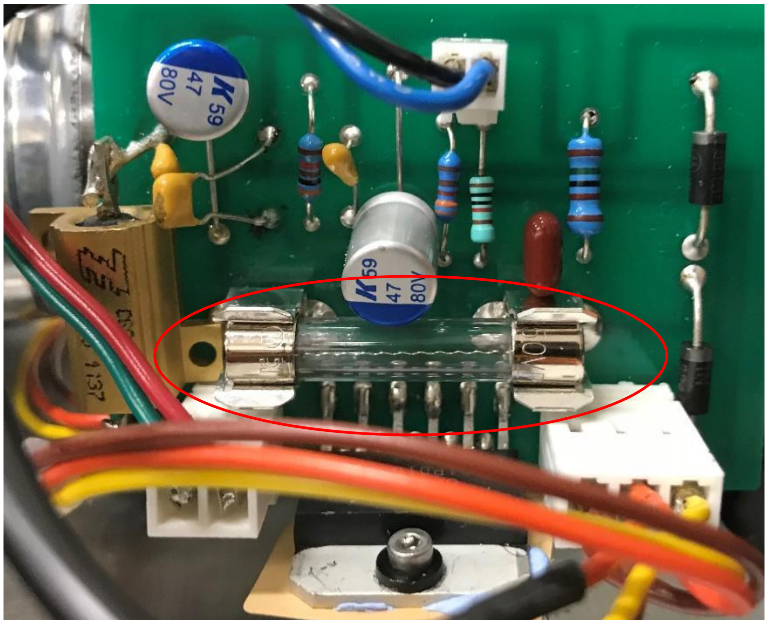


Figure 60: Power Amplifier Fuse

Step 4. Verify that the fuse on board is not open by measuring continuity across the fuse. If fuse is working, proceed to Step 5, if fuse not works, exchange another one.

Step 5. Check potential difference between pin 3 (negative feed in) and the pin 6 (Reference) of the power amplifier(OPA549). If there is potential difference, the electrical board is good, then go to check the potential difference of R5.

Step 6. If there is a potential difference, the electrical board is good, then go to check mechanical parts. If no potential difference, replace R5.

Step 7. Verify incoming signal to robot is present (from myRIO), blue color wire is control signal, black color wire is ground. If voltage is present, proceed to Step 8.

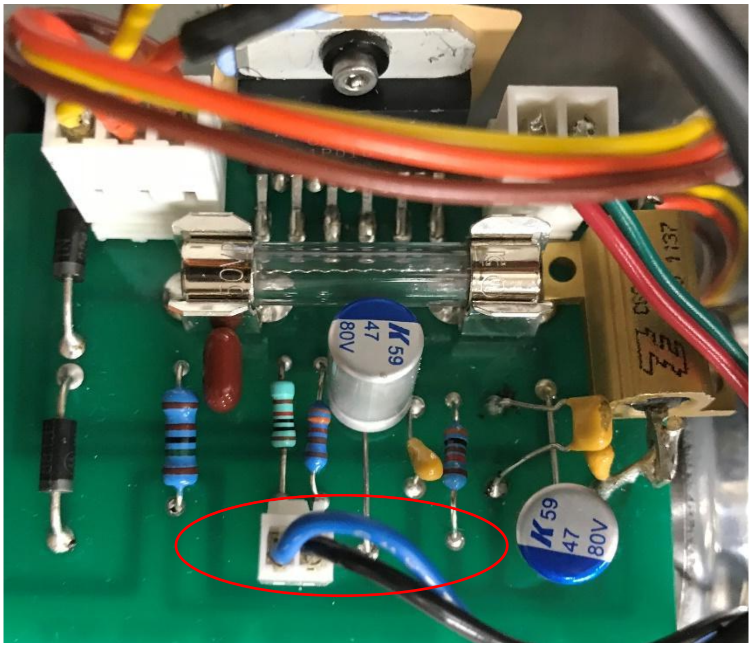


Figure 61: Power Amplifier

Step 8. Check potential difference between pin 4 (positive feed in) and the pin 6 (Reference) of the power amplifier(OPA549). If there is potential difference, the myRIO is good. If no potential difference, reconnect myRIO with the board.

Step 9. Inspect PCB wiring and ensure all plugs are securely fastened.

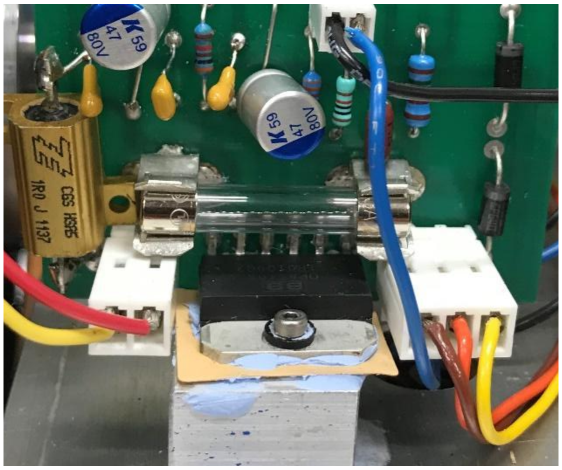


Figure 62: Heat Sink Chip of Power Amplifier

Step 10. Verify the temperature of the chips is not hot. If the chip is hot, unplug the power supply wires let the chips cool down or use fan to cool it.

Step 11. Ensure display board is not wet and no debris is present.

References

- User guide and specifications NI myRIO-1900
- Battery - https://www.amazon.com/TalentCell-Rechargeable-12000mAh-Multi-led-indicator/dp/B078T7M9HZ?th=1
- Encoder Specs - http://www.mouser.com/ds/2/307/e6b2-c_ds_csm491-25665.pdf
- Encoder pic - https://yncync.en.made-in-china.com/product/PvFmpDduCrUB/China-Yumo-E6b2-Cwz3e-100PPR-5V-12V-DC-Shaft-Incremental-Rotary-Encoder.html
- IMU - https://www.sparkfun.com/products/13762
- Arduino - https://store.arduino.cc/usa/arduino-uno-rev3
- XBee - https://www.sparkfun.com/products/8665
- Joystick - similar to: https://www.robotshop.com/ca/en/2-axis-joystick-module.html

Appendix A: Manufacturing Drawings (Brendan Cook and Eric Holakiewicz)

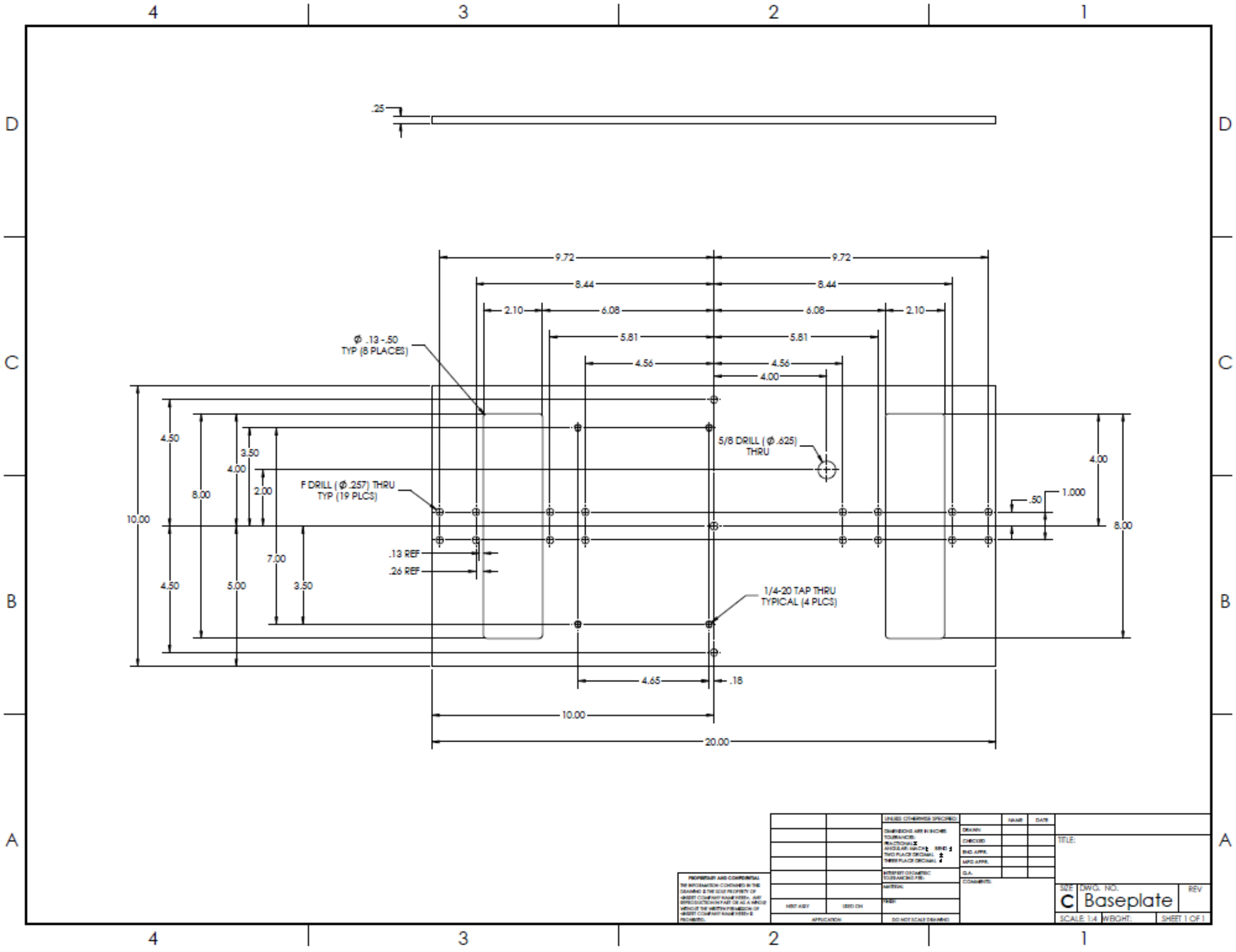
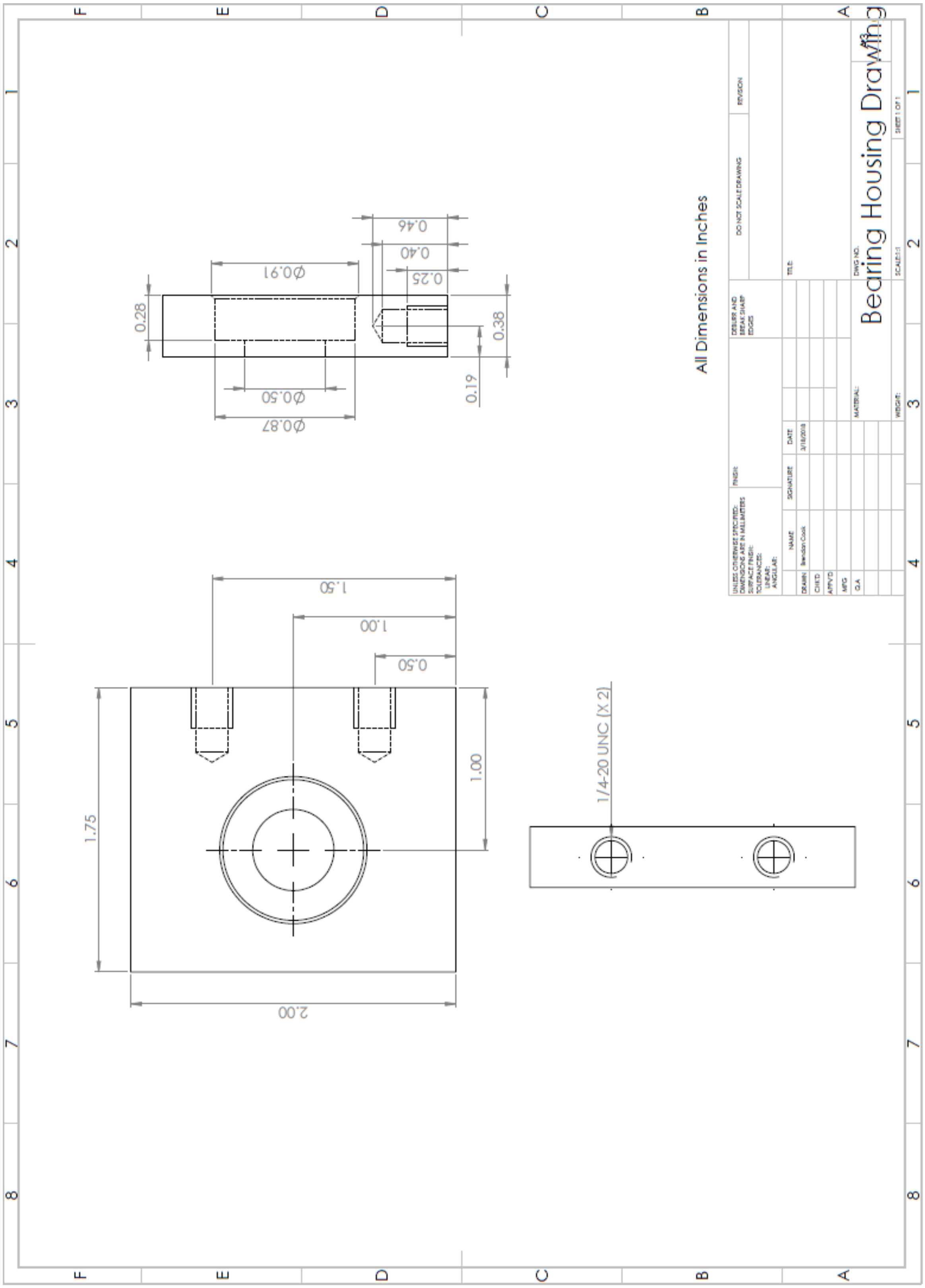
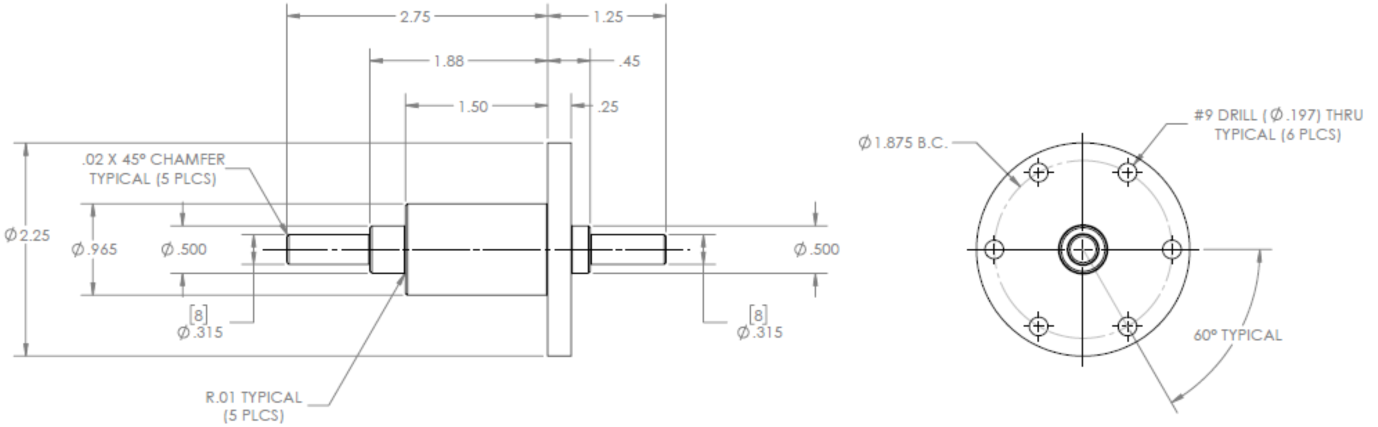

4
3
2
1
D
C
B
A
.25
9.72
9.72
8.44
8.44
2.10
6.08
6.08
2.10
5.81
5.81
4.56
4.56
4.00
ϕ .13 -.50
TYP (8 PLACES)
5/8 DRILL (ϕ .625)
THRU
4.00
.50
1.000
8.00
10.00
4.50
3.50
4.00
8.00
2.00
F DRILL (ϕ .257) THRU
TYP (19 PLCS)
7.00
.13 REF
.26 REF
4.50
5.00
3.50
1/4-20 TAP THRU
TYPICAL (4 PLCS)
4.65
.18
10.00
20.00
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
C
DWG. NO.
Baseplate
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1

Figure 63: Baseplate Drawing





PROPRIETARY AND CONFIDENTIAL

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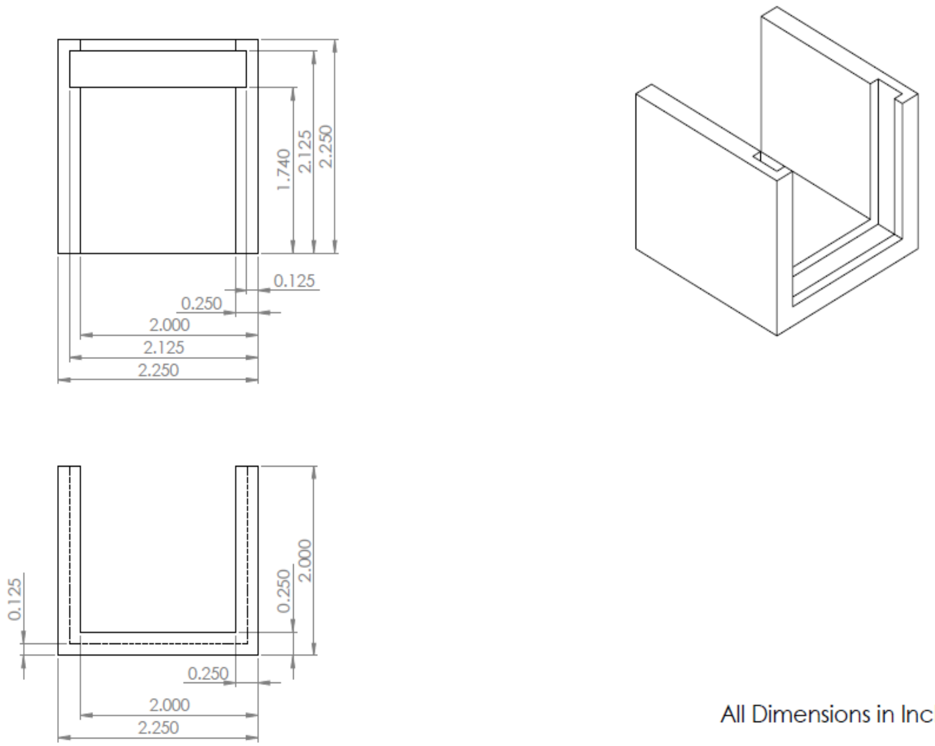
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN CHECKED ENG APPR. MFG APPR. Q.A.			TITLE:
		INTERPRET GEOMETRIC TOLERANCING PER:	COMMENTS:			
		MATERIAL				SIZE **B** DWG. NO. Shaft REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1



All Dimensions in Inches

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Brendan Cook		05/05/2018
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
ABS Plastic

DWG NO.
encoder cover drawing

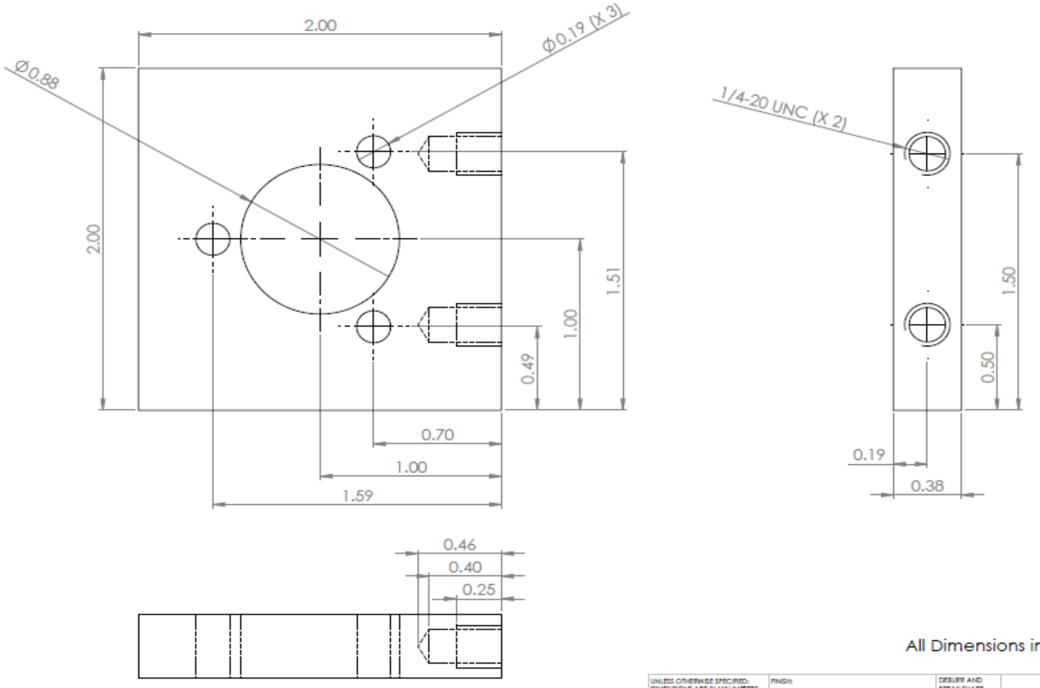
A3

WEIGHT:

SCALE:1:1

SHEET 1 OF 1

Figure 66: Encoder Cover Drawing



All Dimensions in Inches

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	Brendan Cook		3/18/2018			
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:	DWG NO. Encoder Mount Drawing	A3
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1

Figure 67: Encoder Mount Drawing

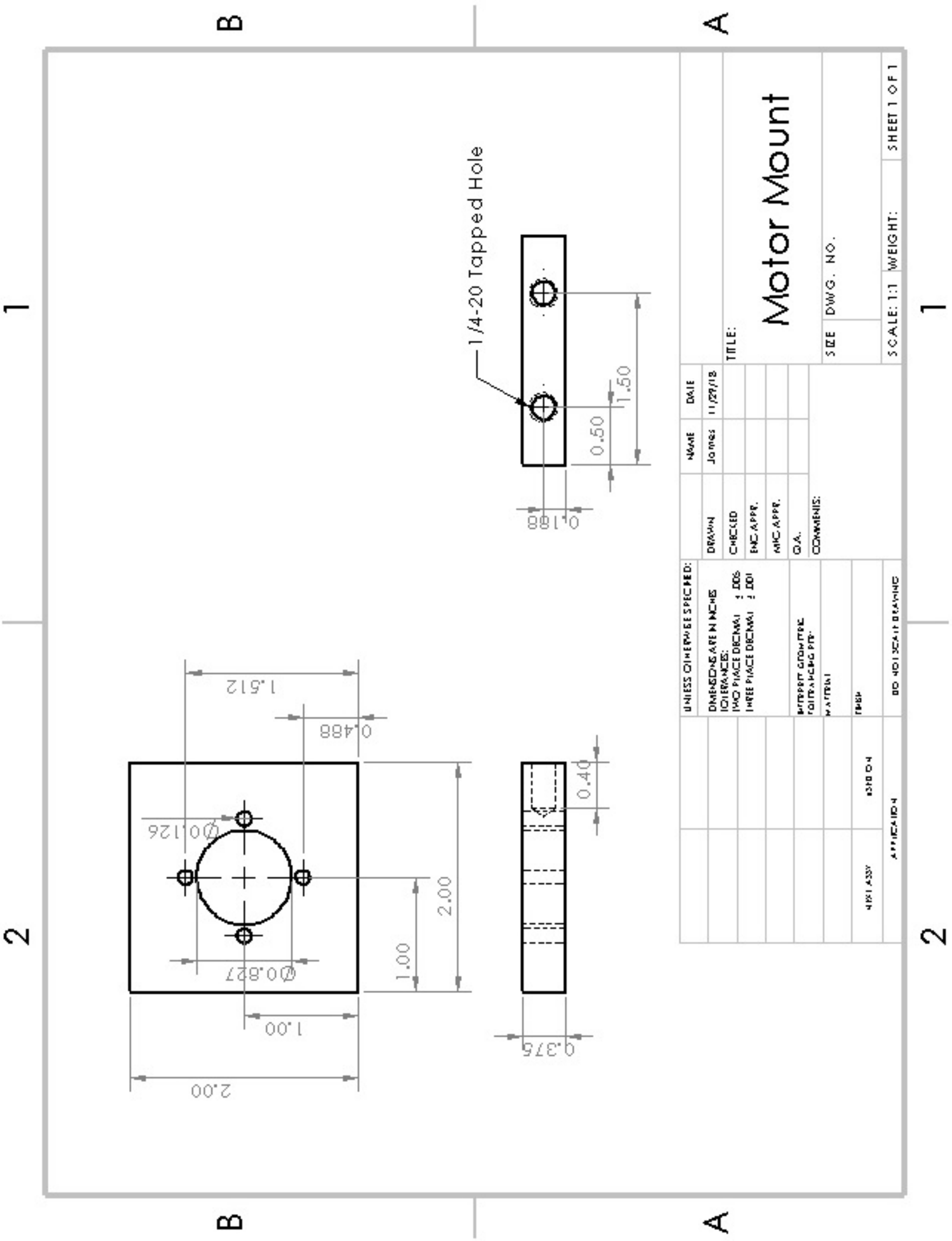
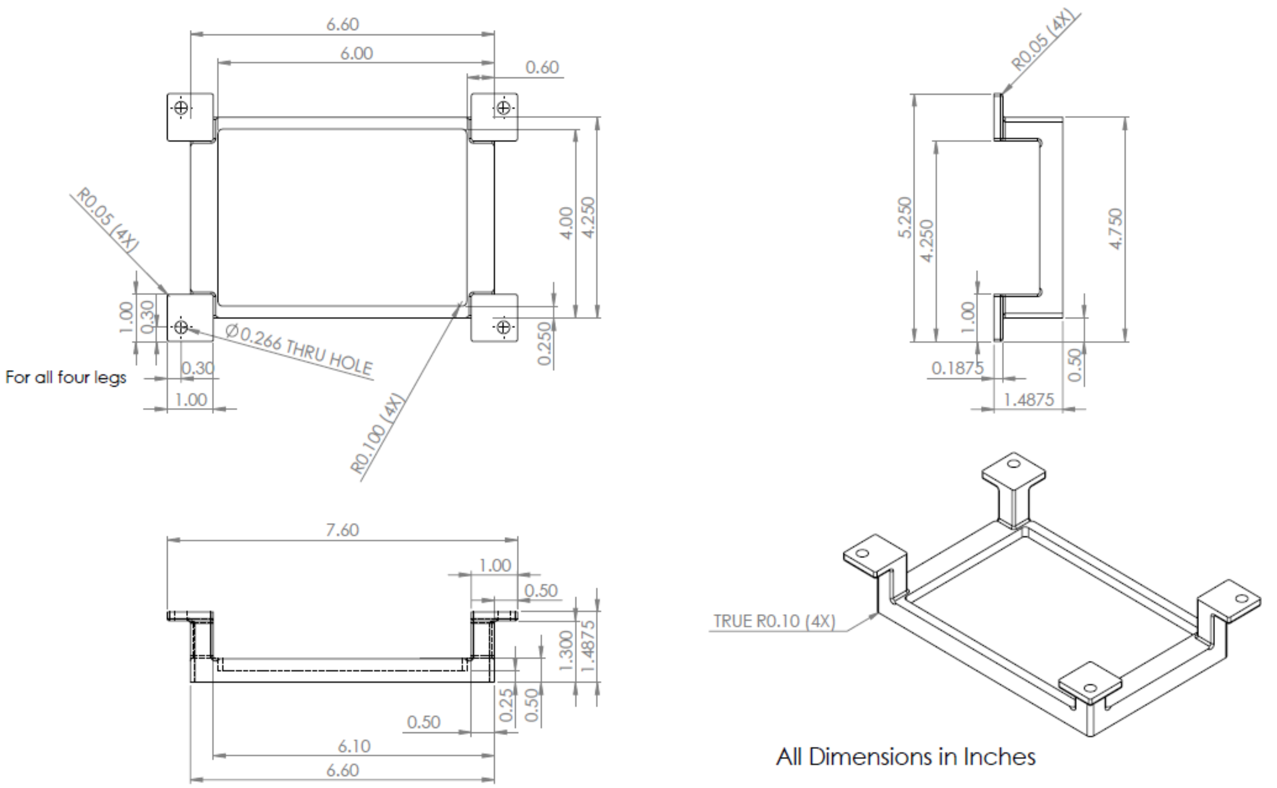


Figure 68: Motor Mount Drawing



All Dimensions in Inches

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:				DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Brendan Cook		05/05/2018				
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: ABS Plastic		DWG NO. myRio_cover drawing	A3
				WEIGHT:		SCALE:1:2	SHEET 1 OF 1

Figure 69: myRIO Cover Drawing

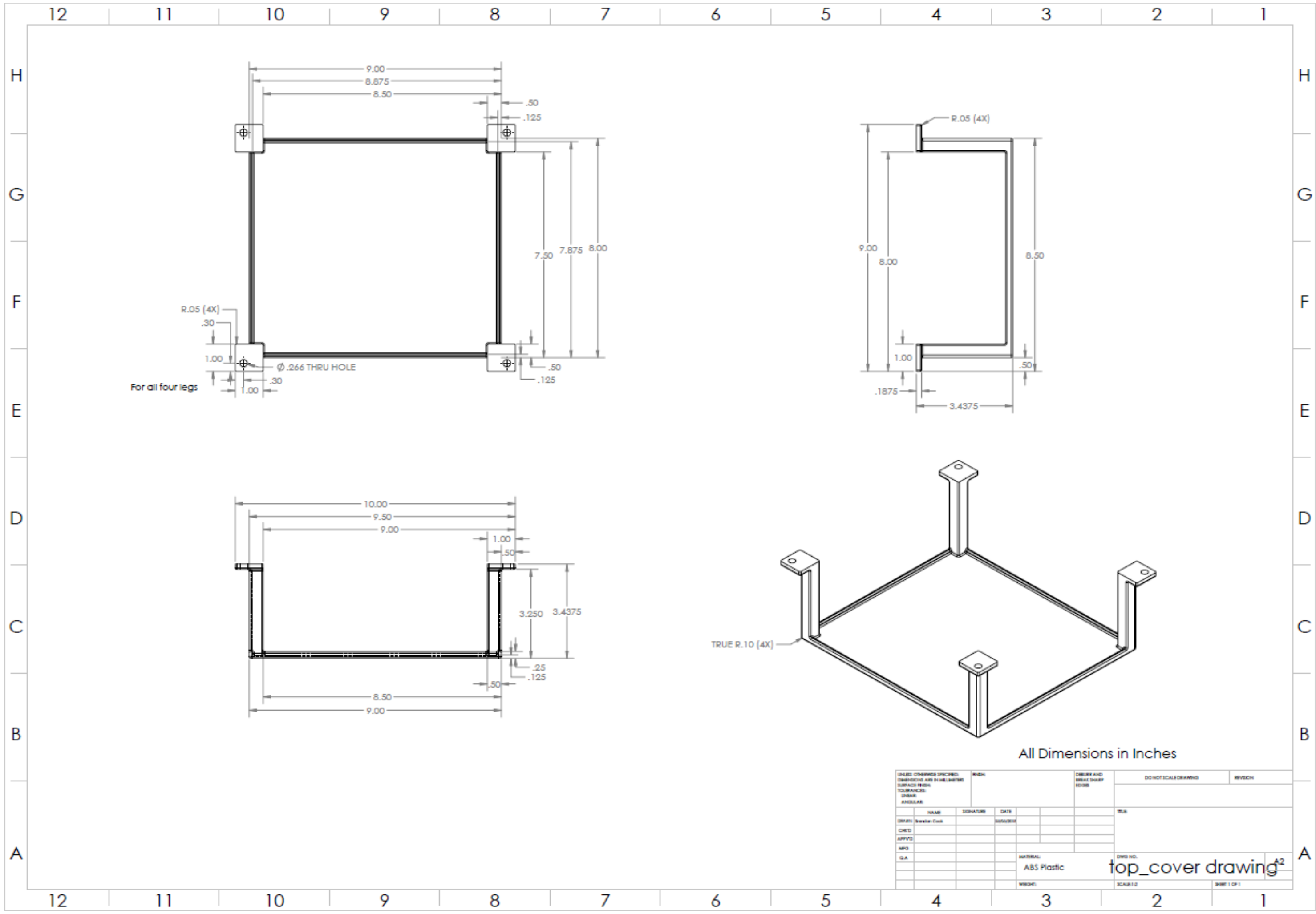
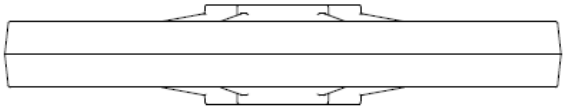
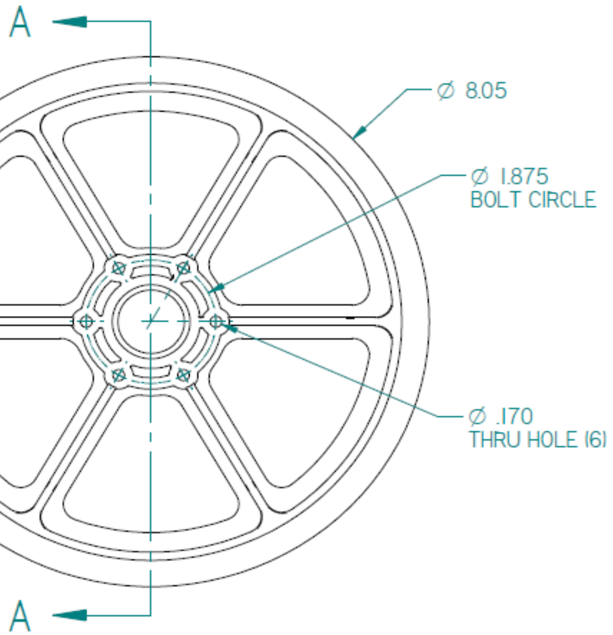
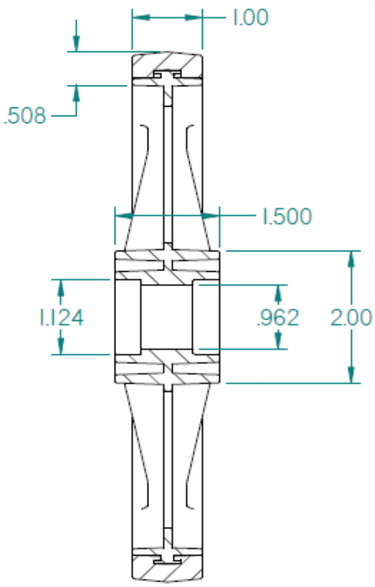

9.00
8.875
8.50
.50
.125
7.50
7.875
8.00
R.05 (4X)
.30
1.00
Ø .266 THRU HOLE
.30
1.00
For all four legs
R.05 (4X)
9.00
8.00
8.50
1.00
.50
.1875
3.4375
10.00
9.50
9.00
1.00
.50
3.250
3.4375
.25
.125
.50
8.50
9.00
TRUE R.10 (4X)
All Dimensions in Inches
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Brandon Cook
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
ABS Plastic
DWG NO.
top_cover drawing
A2
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
12
11
10
9
8
7
6
5
4
3
2
1
H
G
F
E
D
C
B
A

Figure 70: Top Cover Drawing

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED







SECTION A-A

	NAME	DATE
DRAWN	Andy Baker	01/07/10
CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.5°
2 PL ±0.01, 3 PL ±0.005

AndyMark.biz
Standard Solutions for Competition Robots

TITLE 2010 8" FIRST Wheel

SIZE	DWG NO	REV
A2	2010 8 wheel.dft	1

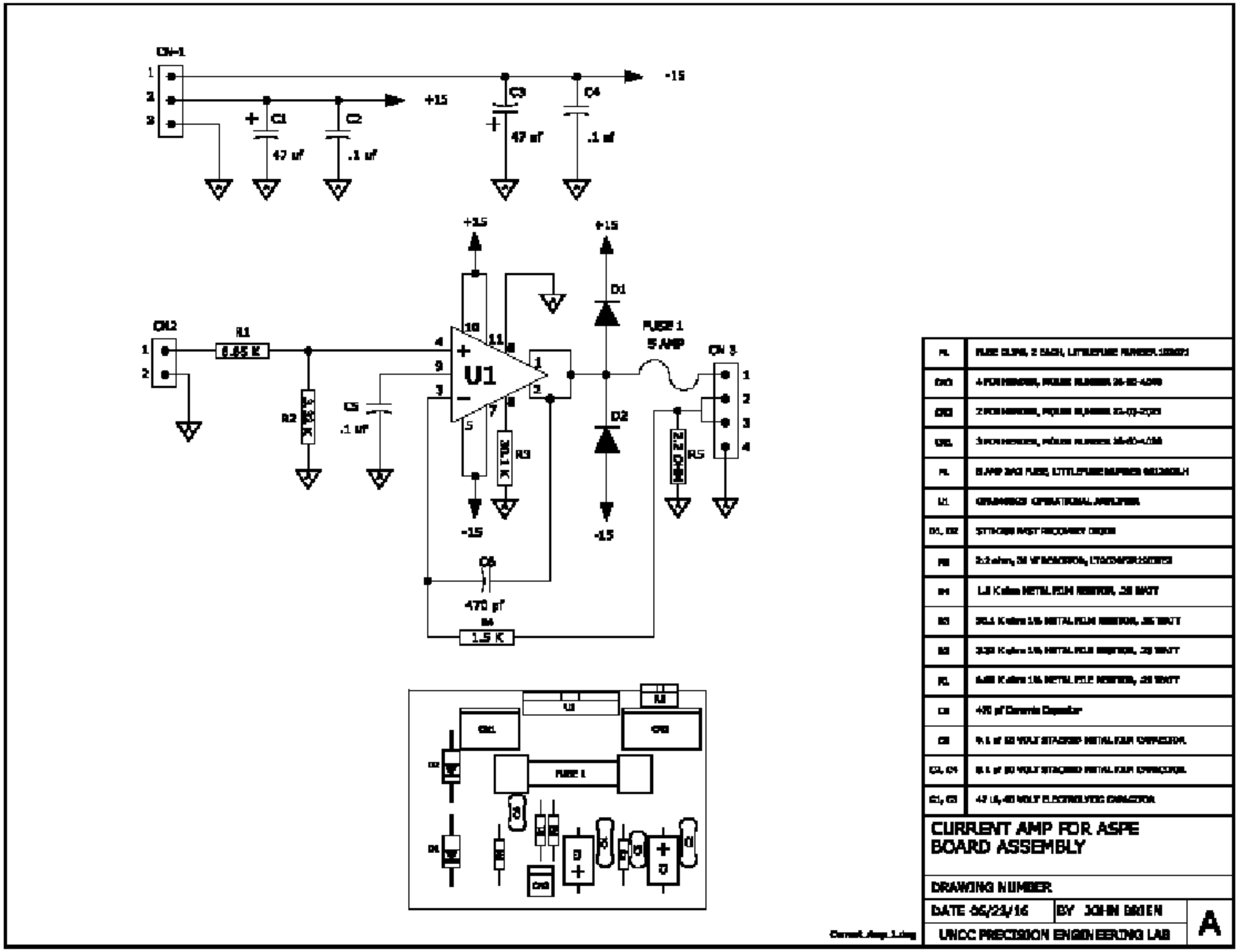
FILE NAME: 2010 8 wheel.dft

SCALE: | WEIGHT: | SHEET 1 OF 1

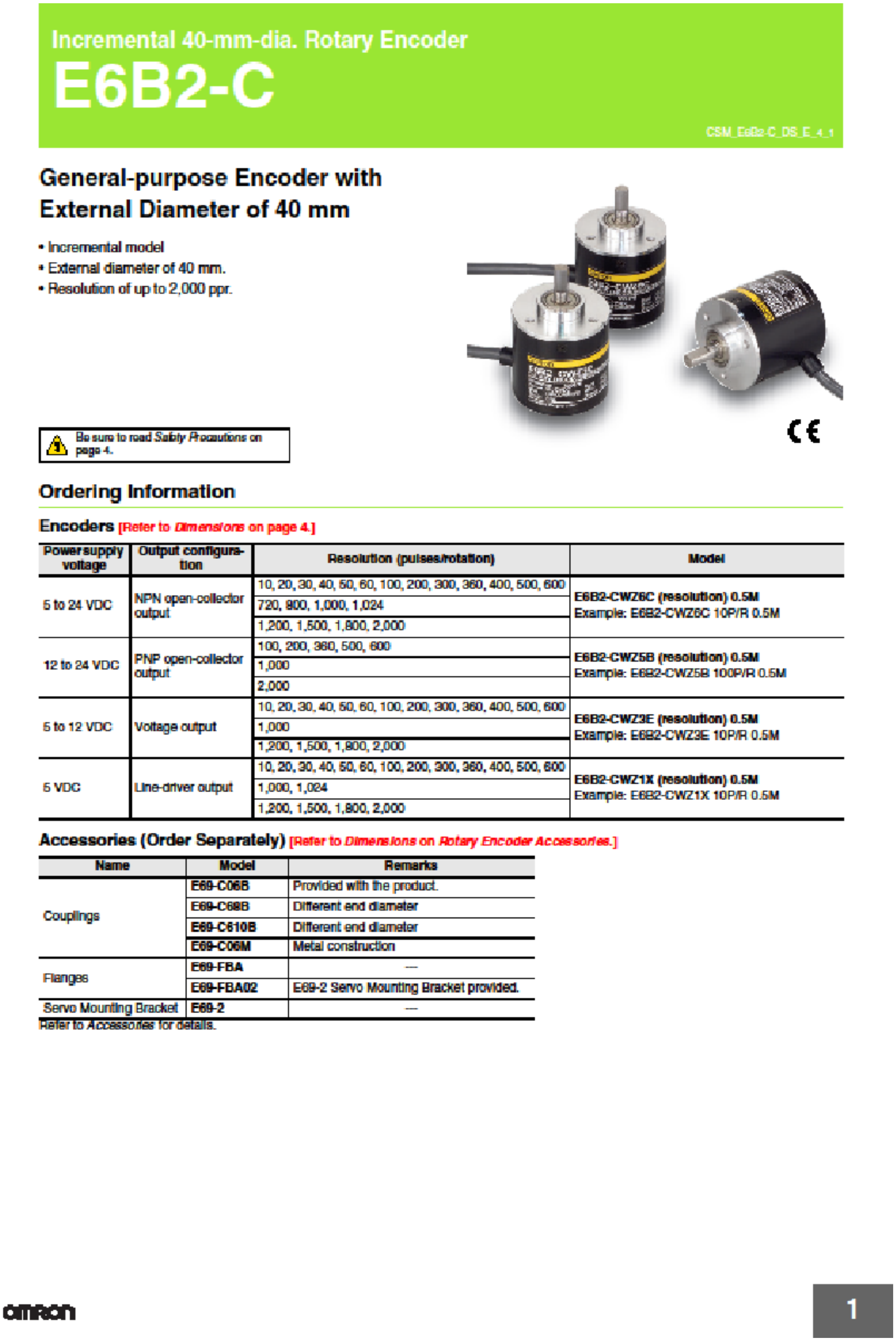
Figure 71: 8 in Plastic Wheel Drawing

Appendix B: Datasheets (Rafi Marandi and Kristen Venditti)

Power Amplifier


CN-1
1
2
3
C1
47 uf
C2
.1 uf
+15
C3
47 uf
C4
.1 uf
-15
CN2
1
2
R1
6.65 K
R2
3.32 K
C5
.1 uf
+15
-15
U1
4
9
3
10
11
5
7
8
1
2
R3
30.1 K
C6
470 pf
R4
1.5 K
+15
D1
D2
-15
FUSE 1
5 AMP
CN 3
1
2
3
4
R5
2.2 OHM
CN1
CN2
CN3
U1
FUSE 1
D1
D2
C1
C2
C3
C4
C5
C6
R1
R2
R3
R4
R5
F1
FUSE CLIPS, 2 EACH, LITTLEFUSE NUMBER 102071
CN3
4 PIN HEADER, MOLEX NUMBER 26-60-4040
CN2
2 PIN HEADER, MOLEX NUMBER 22-03-2021
CN1
3 PIN HEADER, MOLEX NUMBER 26-60-4030
F1
5 AMP 3AG FUSE, LITTLEFUSE NUMBER 0312005.H
U1
[illegible] OPERATIONAL AMPLIFIER
D1, D2
STTH3R06 FAST RECOVERY DIODE
R5
2.2 ohm, [illegible]
R4
1.5 K ohm METAL FILM RESISTOR, .25 WATT
R3
30.1 K ohm 1% METAL FILM RESISTOR, .25 WATT
R2
3.32 K ohm 1% METAL FILM RESISTOR, .25 WATT
R1
6.65 K ohm 1% METAL FILM RESISTOR, .25 WATT
C6
470 pf Ceramic Capacitor
C5
0.1 uf 50 VOLT STACKED METAL FILM CAPACITOR
C2, C4
0.1 uf 50 VOLT STACKED METAL FILM CAPACITOR
C1, C3
47 Uf, 40 VOLT ELECTROLYTIC CAPACITOR
CURRENT AMP FOR ASPE
BOARD ASSEMBLY
DRAWING NUMBER
DATE 06/21/16
BY JOHN BRIEN
UNCC PRECISION ENGINEERING LAB
A
Current_Amp_1.dwg

Encoder



Incremental 40-mm-dia. Rotary Encoder

E6B2-C

CSM_E6B2-C_DS_E_4_1

General-purpose Encoder with External Diameter of 40 mm

- Incremental model
- External diameter of 40 mm.
- Resolution of up to 2,000 ppr.

CE

⚠ Be sure to read *Safety Precautions* on page 4.

Ordering Information

Encoders [Refer to *Dimensions* on page 4.]

Power supply voltage	Output configuration	Resolution (pulses/rotation)	Model
5 to 24 VDC	NPN open-collector output	10, 20, 30, 40, 50, 60, 100, 200, 300, 360, 400, 500, 600	**E6B2-CWZ6C (resolution) 0.5M** Example: E6B2-CWZ6C 10P/R 0.5M
		720, 800, 1,000, 1,024	
		1,200, 1,500, 1,800, 2,000	
12 to 24 VDC	PNP open-collector output	100, 200, 360, 500, 600	**E6B2-CWZ5B (resolution) 0.5M** Example: E6B2-CWZ5B 100P/R 0.5M
		1,000	
		2,000	
5 to 12 VDC	Voltage output	10, 20, 30, 40, 50, 60, 100, 200, 300, 360, 400, 500, 600	**E6B2-CWZ3E (resolution) 0.5M** Example: E6B2-CWZ3E 10P/R 0.5M
		1,000	
		1,200, 1,500, 1,800, 2,000	
5 VDC	Line-driver output	10, 20, 30, 40, 50, 60, 100, 200, 300, 360, 400, 500, 600	**E6B2-CWZ1X (resolution) 0.5M** Example: E6B2-CWZ1X 10P/R 0.5M
		1,000, 1,024	
		1,200, 1,500, 1,800, 2,000	

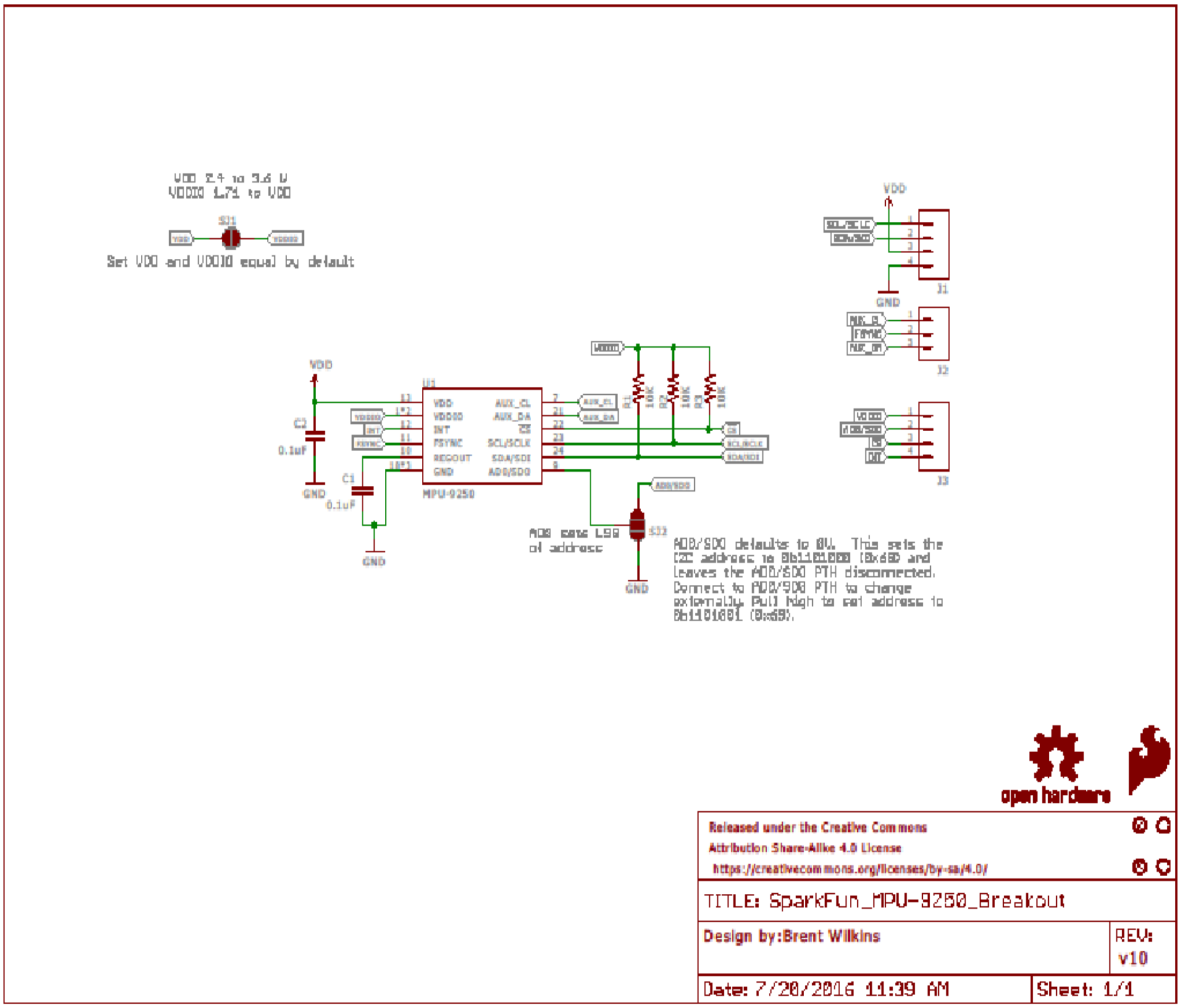
Accessories (Order Separately) [Refer to *Dimensions* on *Rotary Encoder Accessories*.]

Name	Model	Remarks
Couplings	**E69-C06B**	Provided with the product.
	E69-C68B	Different end diameter
	E69-C610B	Different end diameter
	E69-C06M	Metal construction
Flanges	**E69-FBA**	---
	E69-FBA02	E69-2 Servo Mounting Bracket provided.
Servo Mounting Bracket	**E69-2**	---

Refer to *Accessories* for details.

OMRON

IMU



VDD 2.4 to 3.6 V
VDDIO 1.71 to VDD

Set VDD and VDDIO equal by default

AD0 sets LSB of address

AD0/SDO defaults to 0V. This sets the I2C address to 0b1101000 (0x68) and leaves the AD0/SDO PTH disconnected. Connect to AD0/SDO PTH to change externally. Pull high to set address to 0b1101001 (0x69).

TITLE: SparkFun_MPU-9250_Breakout

Design by:Brent Wilkins

REV: v10

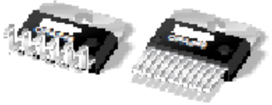
Date: 7/20/2016 11:39 AM

Sheet: 1/1

Op-Amp

Burr-Brown Products
from Texas Instruments

OPA549



High-Voltage, High-Current OPERATIONAL AMPLIFIER

FEATURES

- HIGH OUTPUT CURRENT:
  8A Continuous
  10A Peak
- WIDE POWER-SUPPLY RANGE:
  Single Supply: +8V to +60V
  Dual Supply: ±4V to ±30V
- WIDE OUTPUT VOLTAGE SWING
- FULLY PROTECTED:
  Thermal Shutdown
  Adjustable Current Limit
- OUTPUT DISABLE CONTROL
- THERMAL SHUTDOWN INDICATOR
- HIGH SLEW RATE: 9V/µs
- CONTROL REFERENCE PIN
- 11-LEAD POWER PACKAGE

APPLICATIONS

- VALVE, ACTUATOR DRIVERS
- SYNCHRO, SERVO DRIVERS
- POWER SUPPLIES
- TEST EQUIPMENT
- TRANSDUCER EXCITATION
- AUDIO POWER AMPLIFIERS

DESCRIPTION

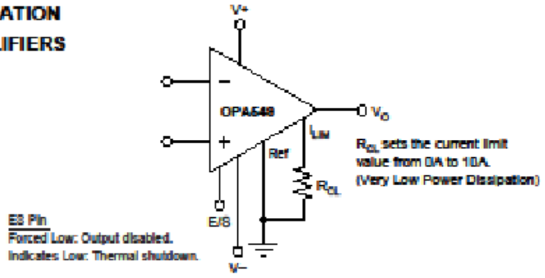
The OPA549 is a low-cost, high-voltage/high-current operational amplifier ideal for driving a wide variety of loads. This laser-trimmed monolithic integrated circuit provides excellent low-level signal accuracy and high output voltage and current.

The OPA549 operates from either single or dual supplies for design flexibility. The input common-mode range extends below the negative supply.

The OPA549 is internally protected against over-temperature conditions and current overloads. In addition, the OPA549 provides an accurate, user-selected current limit. Unlike other designs which use a "power" resistor in series with the output current path, the OPA549 senses the load indirectly. This allows the current limit to be adjusted from 0A to 10A with a resistor/potentiometer, or controlled digitally with a voltage-out or current-out Digital-to-Analog Converter (DAC).

The Enable/Status (E/S) pin provides two functions. It can be monitored to determine if the device is in thermal shutdown, and it can be forced low to disable the output stage and effectively disconnect the load.

The OPA549 is available in an 11-lead power package. Its copper tab allows easy mounting to a heat sink for excellent thermal performance. Operation is specified over the extended industrial temperature range, –40°C to +85°C.


V+
OPA549
V_O
I_LIM
Ref
R_CL
E/S
V–
R_CL sets the current limit value from 0A to 10A. (Very Low Power Dissipation)
ES Pin
Forced Low: Output disabled.
Indicates Low: Thermal shutdown.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

Texas Instruments
www.ti.com

Appendix C: SPI or I2C? (Shamir Bin-Karim)

Inter-integrated Circuit (I2C) and Serial Peripheral Interface (SPI) are two most commonly used serial communications. I2C allows multiple masters and slaves on a bus, where SPI only works with one master device controlling multiple slaves. Both SPI and I2C has their usefulness and problems, depending on the need of the task to be accomplished. The following links are a great resource to learn more about SPI and I2C:

https://learn.sparkfun.com/tutorials/i2c
https://learn.sparkfun.com/tutorials/serial-peripheral-interface-spi