AUTONOMOUS VEHICLE CONTROL PROJECT TECHNICAL MANUAL

version 2.0

GROUP 3

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Style Conventions

The following style conventions are used in this document:

Bold

Names of commands, options, programs, processes, services, and utilities

Names of interface elements (such windows, dialog boxes, buttons, fields, and menus)

Interface elements the user selects, clicks, presses, or types.

Italic

Publication titles referenced in text.

Emphasis (for example a new term)

Variables

`Courier`

System output, such as an error message or script

URLs, complete paths, filenames, prompts, and syntax

Courier italic

Variables on command line

User input variables

< > Angle brackets enclose parameter or variable values supplied by the user.

[ ] Square brackets enclose optional values

| Vertical bar indicates alternate selections - the bar means “or”

{ } Braces indicate content that you must specify (that is, x or y or z)

ABSTRACT

- Project Brief (Jesse Redford, Sunitha Paraselli, Mahfuja A Khuda, Savita More & Somto Anyaegbu)
- System Diagram (Sunitha)
- Parts List and References (Mahfuja, Sunitha, Savita)
- Wiring / Communication (Somto, Sunitha, Savita)
- Control Strategy (Somto, Mahfuja)
- Equations / Conversions / Considerations (Jesse, Somto, Mahfuja)
- Mechanical Constructions (Mahfuja, Sunitha)
- Software Table and File References. (Jesse)
- Start Up Procedure (Jesse)
- Troubleshooting (Jesse)
- References (Sunitha)

1. Introduction

The two wheeled autonomous self-balancing vehicle original prototype was developed by a Mechatronics group at UNC Charlotte mechanical engineering department group in the fall semester of 2018. It was design to self-balance itself and be controlled wirelessly via an Arduino joystick. System was powered by two 24V 82.88Wh Lithium-ion battery with dual outputs of 24V and 12V. The two 24V outputs were connected in series to create a bi-polar power source of peak voltage of +-24V to power the amplifier circuit and the 12V in series to (not bipolar) to power the myRIO. The myRIO embedded device was used as a controller to compute desired control target difference and output control signals to compensate appropriately.

The main objective of this project was improving on the previous designs done by the prior groups in the design and implementation of a two wheeled self-balancing non-autonomous vehicle prototype. The current [redacted]) team was tasked with the following:

- Hardware
  - Design and install new power amplifier circuit.
  - Design and install new mounts for DC motors.
  - Procure and test new charger for the onboard batteries.
  - Procure and install new motors.
  - Test the rest of the hardware systems within the prototype.

- Software
  - Install NI LabVIEW
  - Install myRIO drivers.
  - Create dashboard in LabVIEW for controlling motors and reading sensor data.
  - Verify wireless connection stable wireless connection.

- Mechanical system derivation and controller setup
  - Derive the Lagrangian mechanics of the system.
  - Develop a control strategy.

All tasks were completed with some minor deviations that will explained within this document. An NI LabVIEW software was used to control the robot where an FPGA program is built to read data from the encoder sensor to determine the setpoint velocity and tilt angle of the robot. A cascade controller has been established on LabView myRIO to send a controlled voltage to the motor after comparing with the encoder output to get the desired output required for self-balancing. A Wi-Fi connection has been set with the myRIO to connect with the host laptop wherein a USB port has been used to connect a PS2 Joystick with the host laptop. Below is a pictorial diagram of the system.

Figure 1 An Overview of the Two Wheeled Autonomous Self-Balancing Vehicle

A future improvement can be done in the present prototype by removing the Velcro from the top of the additional mounting plate and by adding three holes to accommodate the myRIO. All other hardware restrictions, i.e., incorrect size of shaft coupler because of which the screw sets of the coupler get restricted by the encoder casing as well as the hex screws of the motor mounts get loose due to its small size, can be improved in the future. Some improvement can be done in the PID controller and to overcome the dead zone of the motor.

1.1 Purpose of this document

This manual covers the design and implementation of a two wheeled autonomous self-balancing vehicle controlled with a wireless controller and myRIO embedded device. Including preparing your hardware and software requirements; and other related components.

2. System Requirements

This Chapter describes the hardware, software and systems materials required to design and build the two-wheeled autonomous self-balancing vehicle.

This chapter includes the following sections:

- Overview
- Hardware requirements
- Software requirements
- Operating systems and software

2.1 Overview

The two wheeled autonomous self-balancing vehicle parts can be designed, programmed, and implemented with physical hardware components. The following hardware and software requirements. User/reader must have some level of python and LabVIEW programming and engineering technical skills to fully understand and implement the system.

2.2 Hardware Requirements

The recommended minimum specifications for the computer and the myRIO device include the following:

Computer:

- x86-based Processor

NI myRIO student embedded device:

- Version 1900

2.3 Software Requirements

The following software are required to be installed on the computer for this project:

- NI-LabVIEW version 19.0f2
- KiCAD version 5.1.10
- Autodesk Inventor version 24 Siena

2.4 Operating Systems

The NI myRIO embedded device operates on the following operating systems:

- NI Linux Real-Time

3. System Construction Setup Overview

This chapter covers the design and construction of the two wheeled autonomous self-balancing vehicle.

3.1 General System Setup and Parts List

The NI myRIO embedded device is used as the main controller in the design of the project. The myRIO is powered by a 12V DC power source. The myRIO receives control feedback from two sensors; The built in 3axis accelerometer of the myRIO (+- 8g range, 12 bits of resolution) and an incremental rotary encoder that are attached to the sides of the wheel.
The myRIO receives it is drive control input reference wirelessly from a joystick pad connected to a computer. The computer connects to the myRIO via a Wi-Fi connection. The based on any of these inputs the controller then decides on the compensation value required. An output control signal is sent out by the myRIO to control the power amplifier circuit, which then amplifies said signal and send it to the motor. The two wheeled autonomous self-balancing vehicle uses a Brushless planetary gear motor to drive itself. The brushless planetary gear motor converts the amplified electrical power to mechanical power (Torque) to drive the system.
Figure 2 is a picture showing all the parts of the two wheeled autonomous self-balancing vehicle. The numbered labels parts correspond to the serial numbers of the hardware part list in the table below.

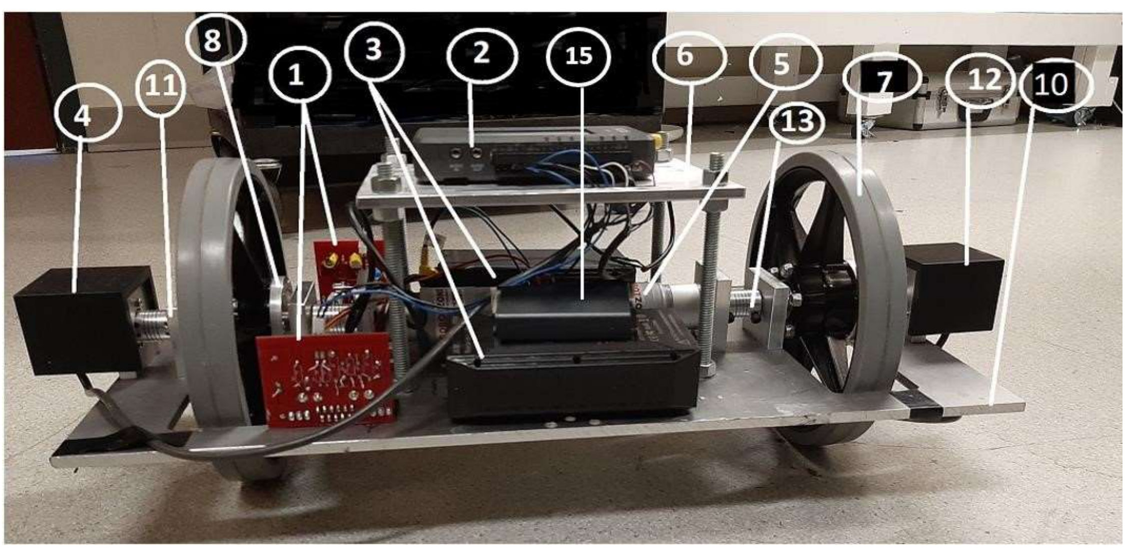

Figure 2 Labelled picture of the two wheeled autonomous self-balancing vehicle.

Figure 3 A picture showing the wireless motion control system.

Table 1 A Tabular Representation of All Hardware Parts and Their Specifications

S/N	Part Name	Quantity	Sub-Components	Specification
1	Power amplifier circuit	2	Capacitor ○ 470pF ○ 0.1μF ○ 47μF Resistors ○ 1.5kΩ ○ 3.32kΩ ○ 12kΩ ○ 30.1kΩ Power Resistor ○ 2.2Ω	• $\pm 24V$ power source • $I_{max} = 2\ Ampere$

			Diodes ◦ STTH208 (2x) Fuse ◦ 5 amp Connector Headers ◦ 2 pin headers(2x) ◦ 3 pin headers Operational Amplifier - OPA549	
2	NI myRIO 1900	1	-	**Refer to datasheet in Appendix B*
3	TalentCell Battery PB240A1	2		• 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” **Comment:** • Batteries sometimes turn off randomly during operation even if fully charged.

4	Incremental rotary encoder	2		● 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 **Comment:** • Wiring / routing needs to be cleaned up.
5	Planetary gear brushless DC motor	2		• 6-12V *Refer to Appendix B. **Comment:** • The motors have a lot of backlash. Either the motors drivers or motors are asymmetric. Must send a higher control voltage to one motor to get the same response as the other.
6	Additional mounting plate for housing myRIO and to improve balance.	1		*Refer to Appendix C. **Comment:** • Hex screws that secure DC motors are very small and can easily become loose and interfere with shaft coupler.
7,9	Wheels	2		*Refer to Appendix C.
8	Wheel bearing	4		*Refer to Appendix C.
10	Base plate	1		*Refer to Appendix C. **Comment:** • Updated with new slots and holes to mount motor brackets and adjusting mounting plate with threaded rod and to set an amplifier to work as a heat sink for the amplifier.

11	Wheel mount/Bearing housing	2		*Refer to Appendix C.
12	Encoder housing	2		*Refer to Appendix C.
13	Threaded Rod	1		*Refer to Appendix C.
14	Shaft coupler	4		*Refer to Appendix C. **Comment:** • Recommend replacing with correct size. Very loose without set screw. Shaft couplers connecting encoders should be checked.
15	18650 Battery	4		*Refer to Appendix B. **Comment:** • Batteries seem loose in case, make sure the housing is properly sealed before system start up.
17	PS2 joystick pad	1		
18	USB flash drive	1		-

The table above lists all the new hardware components used in the development of this system and their major specifications.

3.2 Electrical System

The two wheeled autonomous self-balancing vehicle electrical system is divided into 3 parts: the power supply system, the drive system and wireless control system. Figure 5 shows the amplifier circuit schematic diagram.

3.2.1 Power Supply System

The system has two different power sources, the two TalentCell Batteries PB240A1 and four 18650 Batteries.

The two Talentcell batteries are capable of outputting both 24V and 12V from two separate ports on the battery power pack. The two 24V ports are connected in series to create a bipolar power source of ±24V peak value and a total potential difference of 48V which is used to power the amplifier circuit.

The four 18650 Batteries are connected in series to get a DC voltage value of approximately 16V which Is used to power the myRIO embedded device.

3.2.2 Drive System

The two wheeled autonomous self-balancing vehicle is made up of the amplifier circuit, the two 12V DC planetary gear motor, the myRIO embedded device and the two incremental rotary encoders. Figure 4 below shows the block diagram of the drive system.

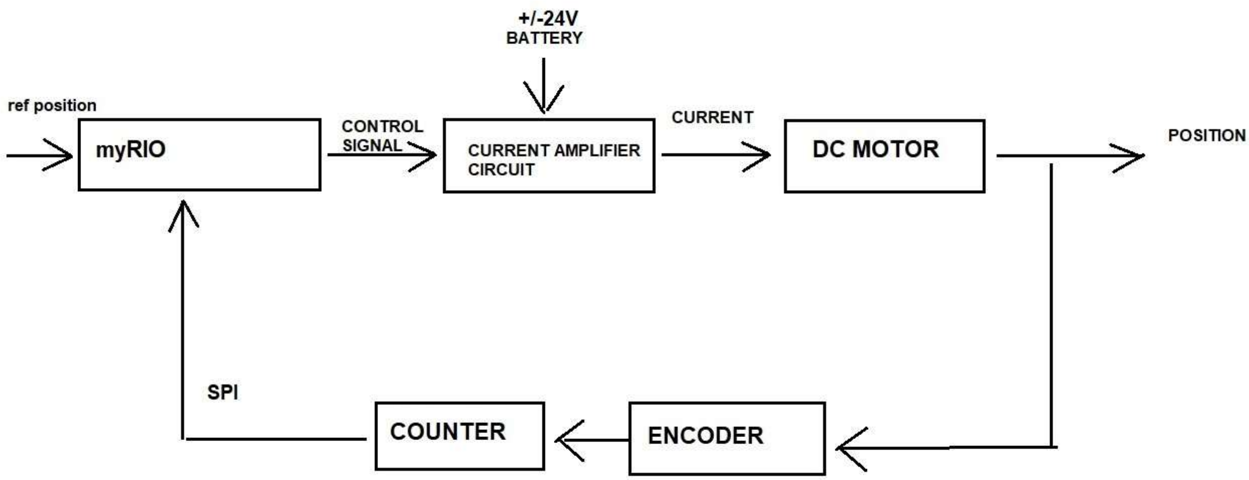

Figure 4 Simple block diagram of the drive system

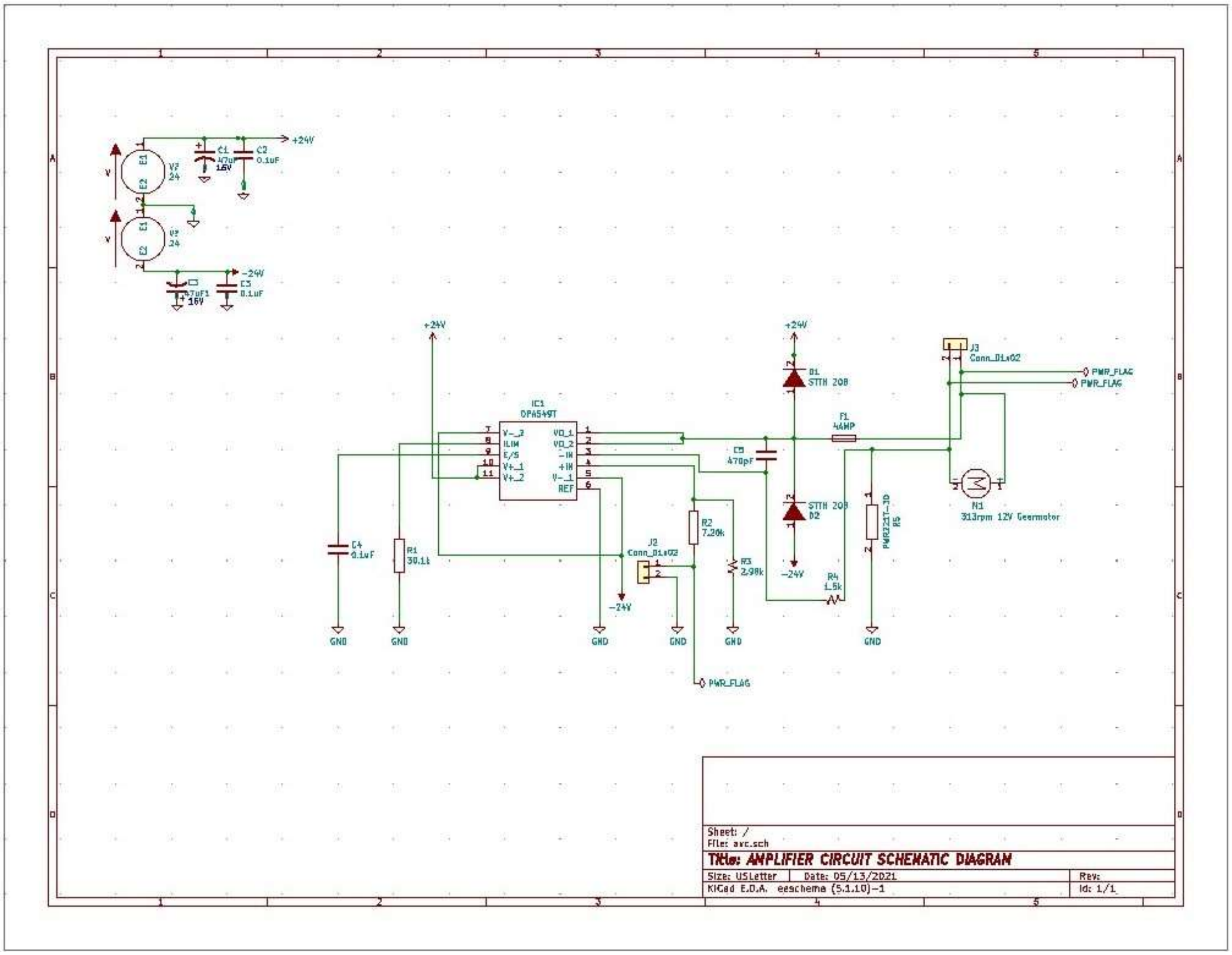

Figure 5 Amplifier Circuit Schematic Diagram

Figure 5 shows the amplifier circuit diagram schematic circuit diagram.

3.2.3 Wireless Controller System

The wireless controller is a PS2 joystick pad connected to laptop which connects the controller wirelessly to the NI myRIO embedded device via a Wi-Fi connection.

3.2.4 Electrical Hardware Wire Connections

Figure 6 below shows the pictorial wiring diagram for the two wheeled autonomous self-balancing vehicle and how the system’s electrical hardware parts are connected.

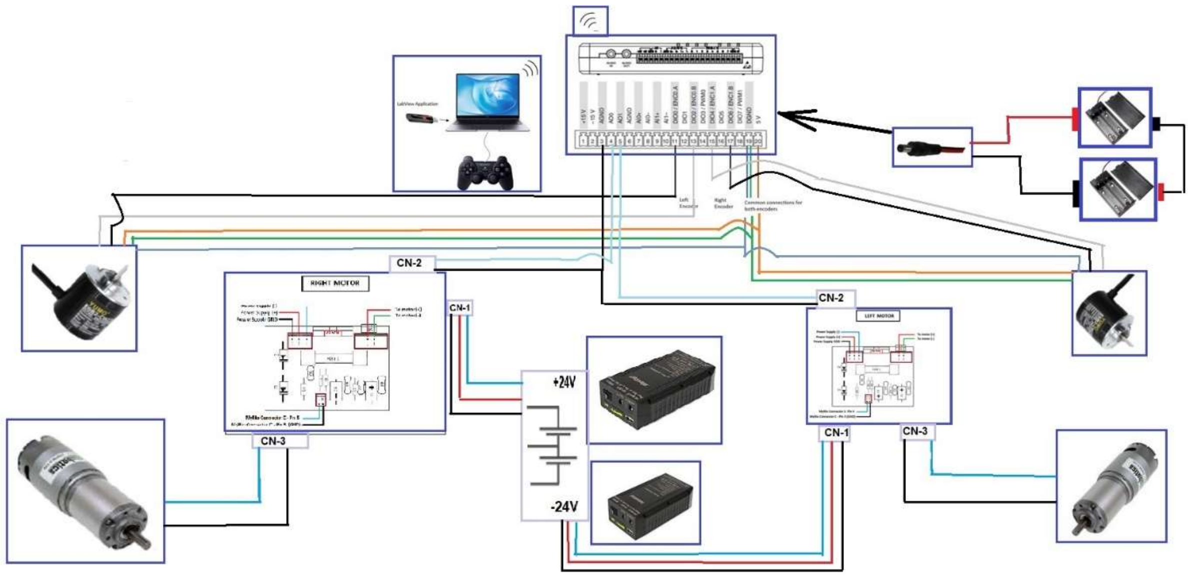

Figure 6 Pictorial wiring diagram of the autonomous self-balancing vehicle

Motors to Power Amplifiers

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

Power Amplifier to Batteries

- 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 and then connected to the batteries negative, positive, and ground.

Power Amplifiers to myRIO Embedded Device

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

3.3 Control System Implementation

The self-balancing system relies on a cascade controller, where 2 PID controllers are aligned in sequence. The first PID compares the robot's current velocity measured by encoders and compares velocity setpoint value provided by the host computer which maps controller inputs to myRIO via shared variables. The control flow follows, output of the first PID sets the tilt setpoint for the second PID controller, which compares the output of the first PID controller with the tilt angle provided by the NI myRIO embedded device's onboard accelerometer. The second PID then outputs the control voltage to DAC which is connected to the power amplifiers which drive current to the motors.

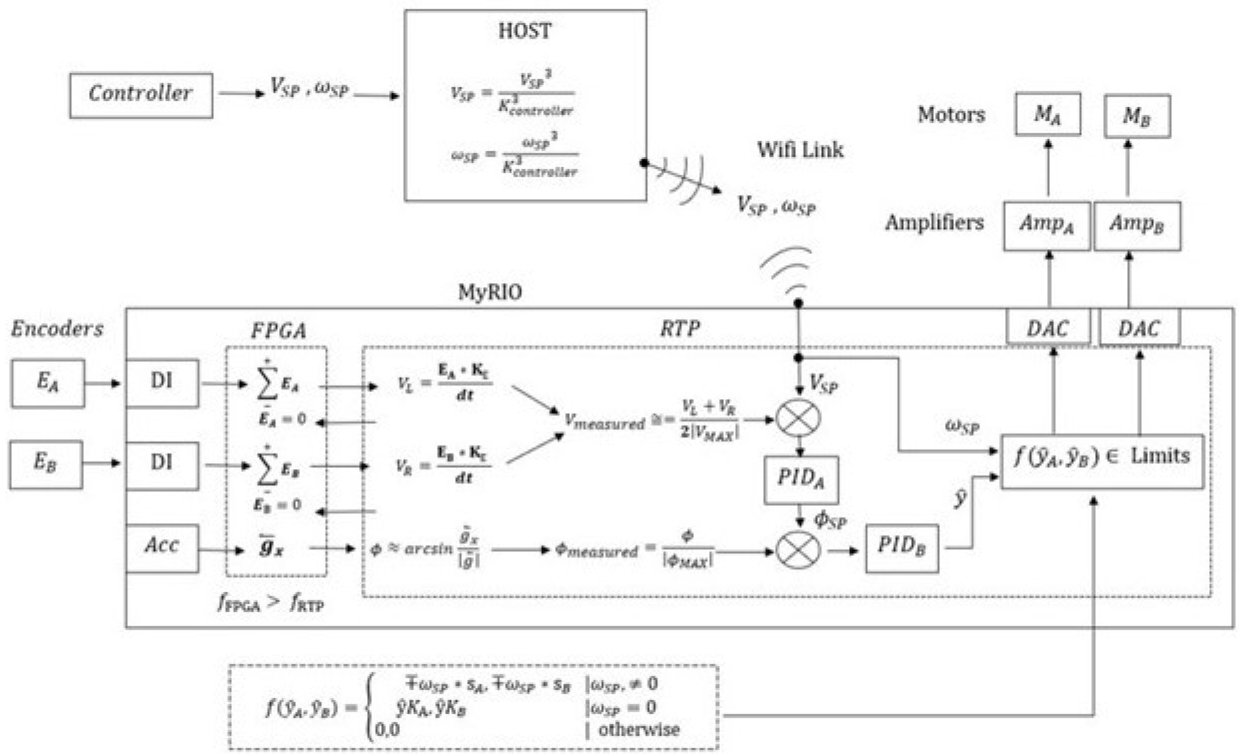

Figure 7 Autonomous self-balancing control system block diagram

3.3.1 Equations, Conversions and Controller Consideration

- Joystick commands, cubic curve normalization.
  - To have better pitch control the control curve from the joystick is normalized using cubic terms.

- Encoders
  - K_e encoder constant (see control system diagram) is computed using manufacturing datasheet and known wheel diameter. This converts the number of encoders clicks to displacement. $K_e = \frac{PPR}{2*Pi*R}^{-1}$, where PPR is pulse per wheel revolution, and R is the radius of the wheel.

- Tilt Normalization
  - The max tilt reading from the accelerometer with the base touching the floor on either side is ± 6. Since this is the max achievable tilt angle for the system it is used to divide future readings by .6 to scale the tilt signal to the domain [-1,1].

- Speed Normalization
  - V_{max} (see control system diagram) was determined by increasing the control voltage output to the motors to some reasonable speed and recording the measured

velocity of the robot from the dashboard. This could be a setting for different operating modes and controls the overall responsiveness of the robot.

- Motor Constant (offset amount)
  - The K_a and K_b constants (see control system diagram) set the desired polarity output to the motors for a given control signal. However, because motor performance differs, i.e., it was found that by multiplying the Left motor by -1.125 rather than just -1.0 to flip the polarity, it gave more symmetric motor responses.

- Control Voltage Output Limit(s).
  - This is not included in the control dashboard in NI LabVIEW. It serves as a failsafe in the RTP program and limits the control voltage output. myRIO can output up to +10V max. The current motor drivers support up to 3amp max. The output current is given by $I = \frac{CV}{R}$, where CV is control voltage from myRIO and R is the resistance value of the power resistor on the power amplifier circuit, (power resistor is rated 2.2ohm). This should be scaled according to current limits of motors and or batteries as well and verified with a multimeter.

3.4 Software Setup

The Table below represents the software necessary to control the robot. Note the left column represents the hardware in which the software should be installed and right column a brief description of its purpose. Be sure to check the electrical hardware wire connection diagram (Figure 6) before deploying.

Table 2 Software Setup Procedure

S/N	Hardware	LabVIEW File	Purpose
1	Host PC (your laptop)	PC Main.lv	Map's controller inputs to shared variables in the RC main script.
2	myRIO (Processor)	RC Main.lv	Runs the cascade controller which drives the system, the velocity setpoint is given by the shared variable with host pc. The first PID controller compares the robots current speed obtained from encoders to setpoint velocity. The PID then outputs a tilt angle setpoint for the second PID which compares the robot's current tilt (given by accelerometer) and symmetrically increases or decreases the control voltage which controls the amount of current

			applied to the motors (see transconductance amplifiers). See control system diagram for more details.
3	myRIO (FPGA)	FPGA Main.lv	The encoders by default are encoded into the FPGA fabric. This script just ensures a communication link between Processor and FPGA with a simple LED control. Future sensors can be integrated here in the future.
4	Host PC	auto_traveler_controller.py	Cascade controller configured with URDF model of the robot. (Must have the URDF model for this to run) Utilizes PyBullet physics simulator to test control strategies and parameters.

4. Post Construction - Start Up Procedure

To start up the two wheeled autonomous self-balancing vehicle, follow the instructions below. Figure X below shows the front panel of the NI myRIO FPGA front panel.

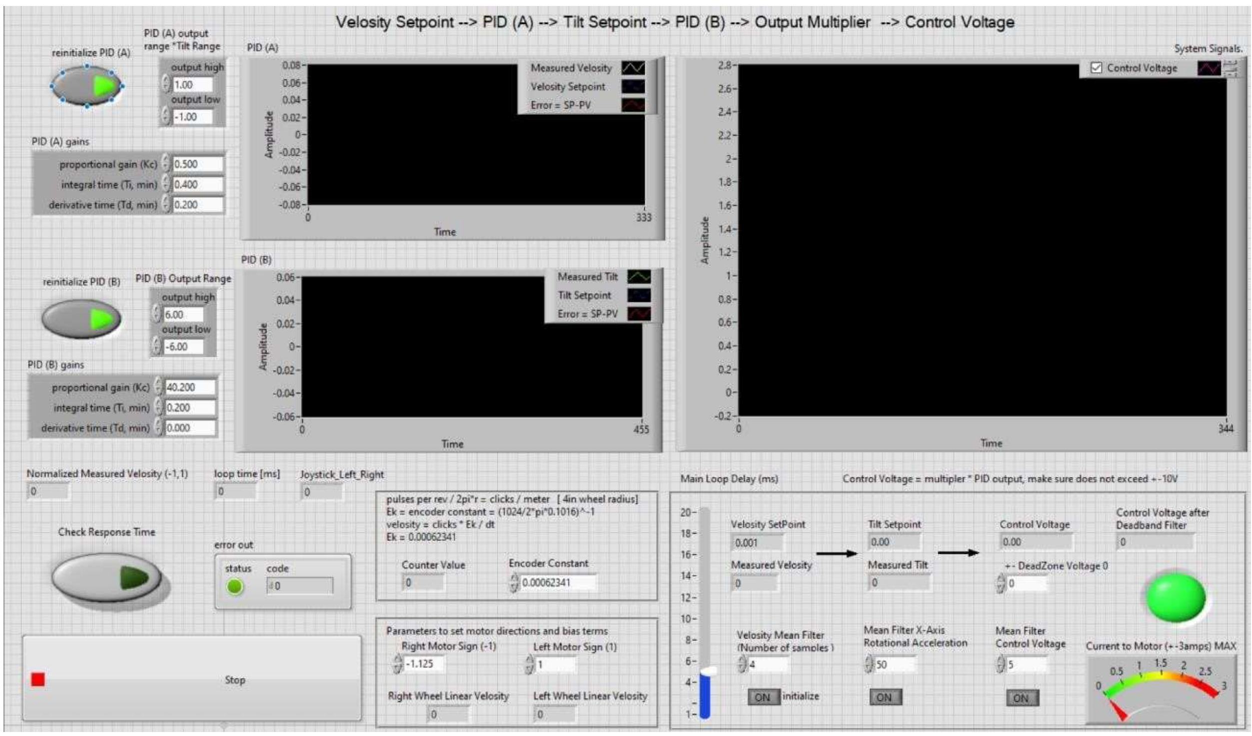

Figure 8 Front panel for NI myRIO FPGA dashboard

- Load the autonmous_robot_application file onto a local machine (laptop or desktop).
- Ensure 1850 batteries are charged and insert onto both onboard battery banks. Plug in myRIO with Jack then ensure both battery pack switches are set to the on position.
- Search for available networks on the local Wi-Fi network will be listed as myRIO, with Password: password. (if using a new myRIO establish connection with your laptop before proceeding).
- If step 3 fails, use USB to establish a communication link with host pc.
- Ensure PS2 Controller is plugged into the host pc.
- Deploy/Run FPGA Main.lv and RT Main.lv on myRIO from host pc.
- Run PC Main.lv
- Inspect Dashboard of RC Main.lv and ensure sensor data is displayed on dashboard.
- Hold the robot up right (balanced) and turn on the battery backs connected to motor drivers.
- Release robot and control with Joystick. Click the X button to terminate RC Main.lv, i.e. the controller. Will need to redeploy RT Main.lv to myRIO to re-initialize the controller.

5. Conclusions and Future Developments

The following consists of desired future modifications to the system.

- Would like to make the controller x button pause the system, deactivate the main control loop, instead of terminating the RTP program.
- Add a flat sequence to allow for systems operation as described above. A 50:1 loop ration between inner to outer was found to work best in simulation. Refer to Figure X below.

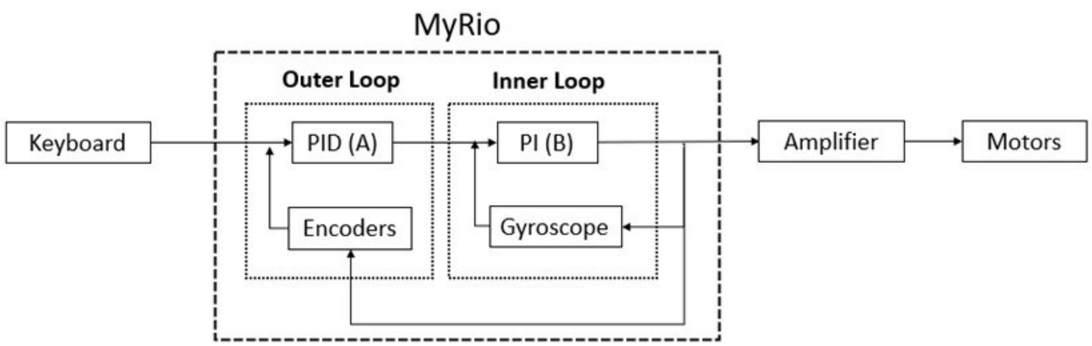

Figure 9 Block diagram of cascade controller

- Install different motors with smaller deadzone and less backlash.
- Implement ways of overcoming the motor deadzone.
- Add a combination of PIR sensors, servomotors and ultrasonic sensors to the robot, and design integrated obstacle avoidance into the control system.
- Fine tuning PID controls constants.
- Remove Velcro from the top of additional mounting plate and add three holes to accommodate myRIO.
- Install correct size of shaft-coupler to avoid conflict with encoder casing and motor bracket screw sets.
- Use larger hex screws in the motor bracket to mount the motor.
- Implement an electrical current feedback-based PI controller for better motor control and performance. Considering the sensor feedback is all electronics it typical runs faster than mechanical feedback (as the time constant involved change in current is lower).

6. References

- [1] C. L. Phillips, H. T. Nagle, and A. Chakrabortty, *Digital Control System Analysis & Design (Fourth Edition).* Pearson, 2015.
- [2] Kevin M. Lynch and Frank C. Park, *Modern Robotics Mechanics, Planning, and Control (1st Edition).* Cambridge University Press, 2017.
- [3] K. Ogata, *Modern Control Engineering (5th Edition).* Pearson, 2009.

7. Appendix A: Acronyms, Abbreviations & Definitions

Details of terms, acronyms, and abbreviations required to properly interpret this document is provided here.

Term	Meaning
PS2	Play Station 2
NI LabVIEW	National Instruments Laboratory Virtual Instrument Engineering Workbench
DC	Direct Current
FPGA	Field-Programmable Gate Array
NI myRIO	National Instruments my Reconfigurable Input Output
GigE	Gigabit Ethernet
IEEE	Institute of Electrical and Electronics Engineers
USB	Universal Serial Bus
PID	Proportional Integral Derivation
i.e	That is to say.
CAD	Computer Aided Design
PC	Personal Computer

8. Appendix B: Related Documentation

#	Document Title	Version #	Location	Author
1	LabVIEW 2019 myRIO Software Bundle	7.0.0	LabVIEW 2019 myRIO Software Bundle Readme - National Instruments (ni.com)	National Instruments
2	USER GUIDE AND SPECIFICATIONS NI myRIO-1900	-	NI myRIO-1900 User Guide and Specifications - National Instruments	National Instruments
3	Plastic 18650 Battery Storage Case Product Specifications	-	Plastic 18650 Battery Storage Case 2 Slots x 3.7V for 2x18650 Batteries Holder Box Container with ON/Off Switch, Set of 5, by Ltvystore)	Ltvystore
4	Past Documentation Report	Fall 2018	Past Documentation Report	MEGR7222 Team 2 – Fall 2018
5	DC Planetary Gear Brush Motor Product Specifications	638280	DC Planetary Gear Brush Motor Specifications - RobotZone	RobotZone
6	Incremental Rotary Encoder Product Specifications	E6B2 – CWZ 6C	Incremental rotary encoder product specification - CYECL	China Yumo Electric Company LTD
7	8 in. SmoothGrip Wheel Product Specifications	am-0420	8 in. SmoothGrip Wheel Product Specification - AndyMark	AndyMark

8	OPA549 High-Voltage, High-Current OPERATIONAL AMPLIFIER Technical Document	-	High-Voltage, High-Current OPERATIONAL AMPLIFIER Technical Document - Burr-Brown Products from Texas Instruments	Burr-Brown Products from Texas Instruments
9	PWR221T-30 Series Power Resistor Technical Document	-	Bourns Power Resistors (digikey.com)	Bourns

Obtaining Documentation

You can access the most current National Instruments documentation on the World Wide Web at the following site: Documentation - NI. For more information on codes and documentation refer to flash drive attached to robot.

9. Appendix C: CAD Drawings

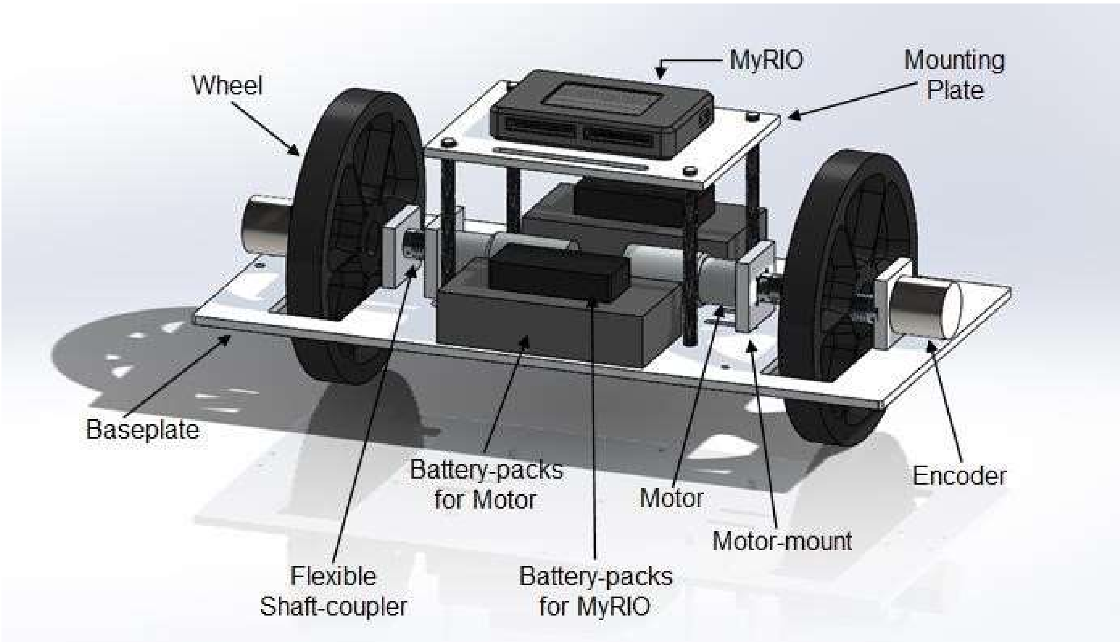

Figure 10 Robot's CAD model

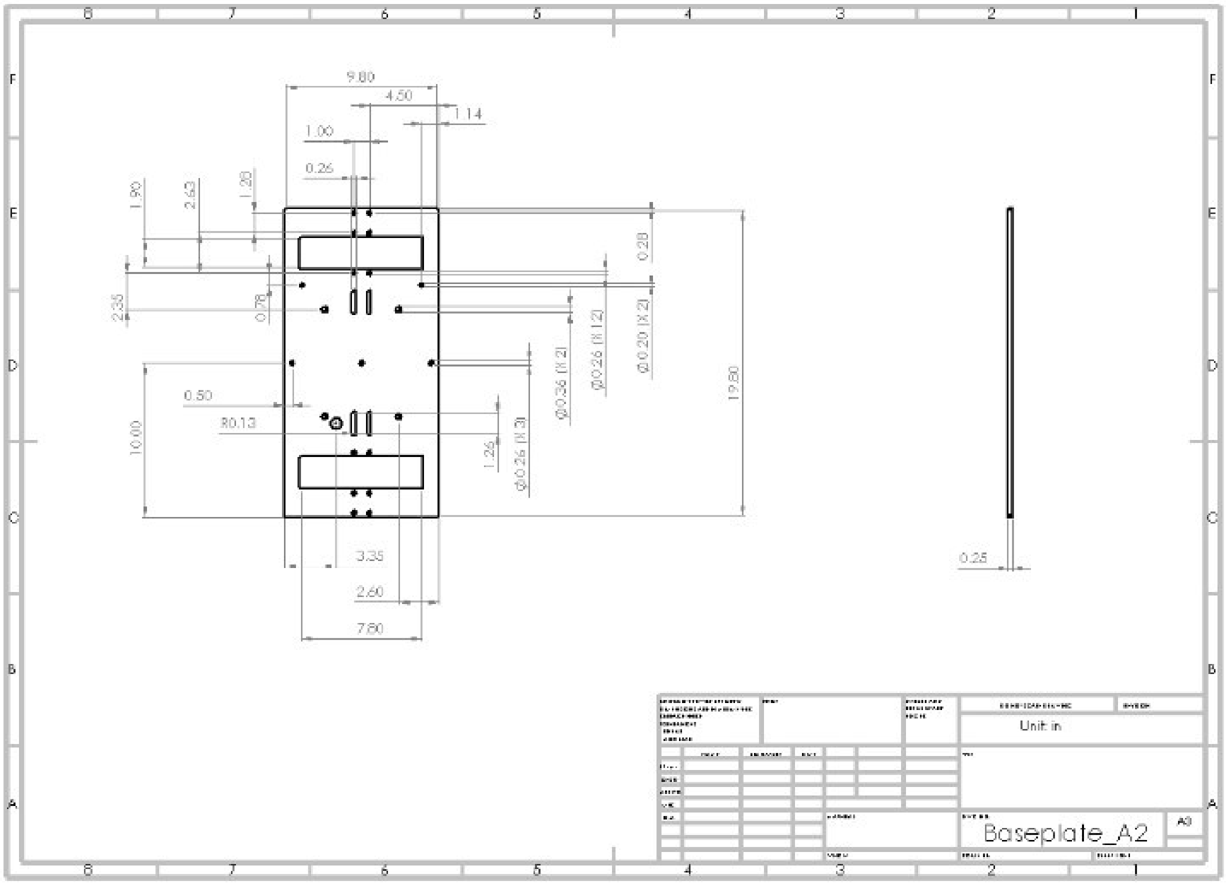

Figure 11 Update base plate drawing

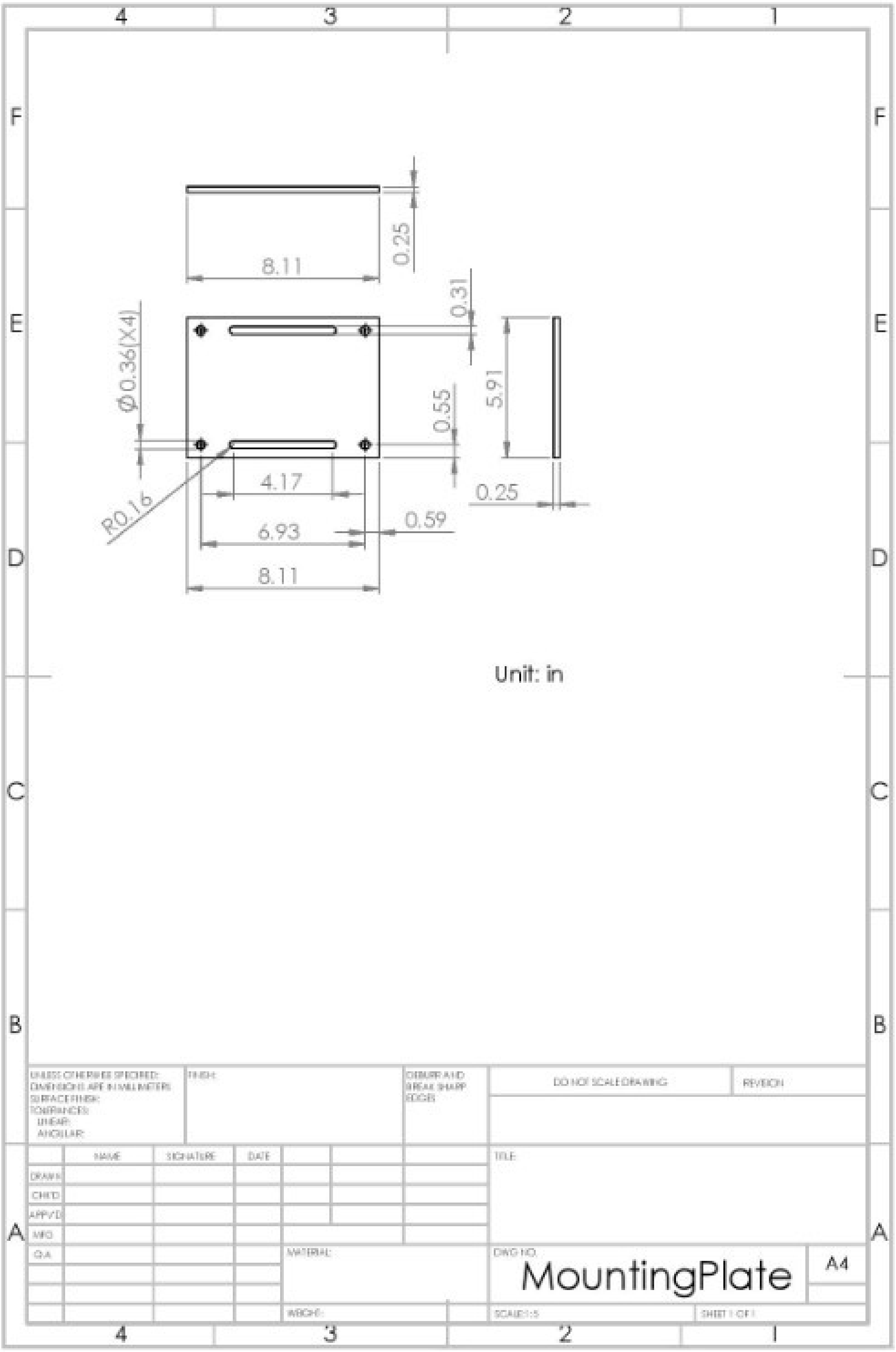

Figure 12 Additional mounting plate drawing

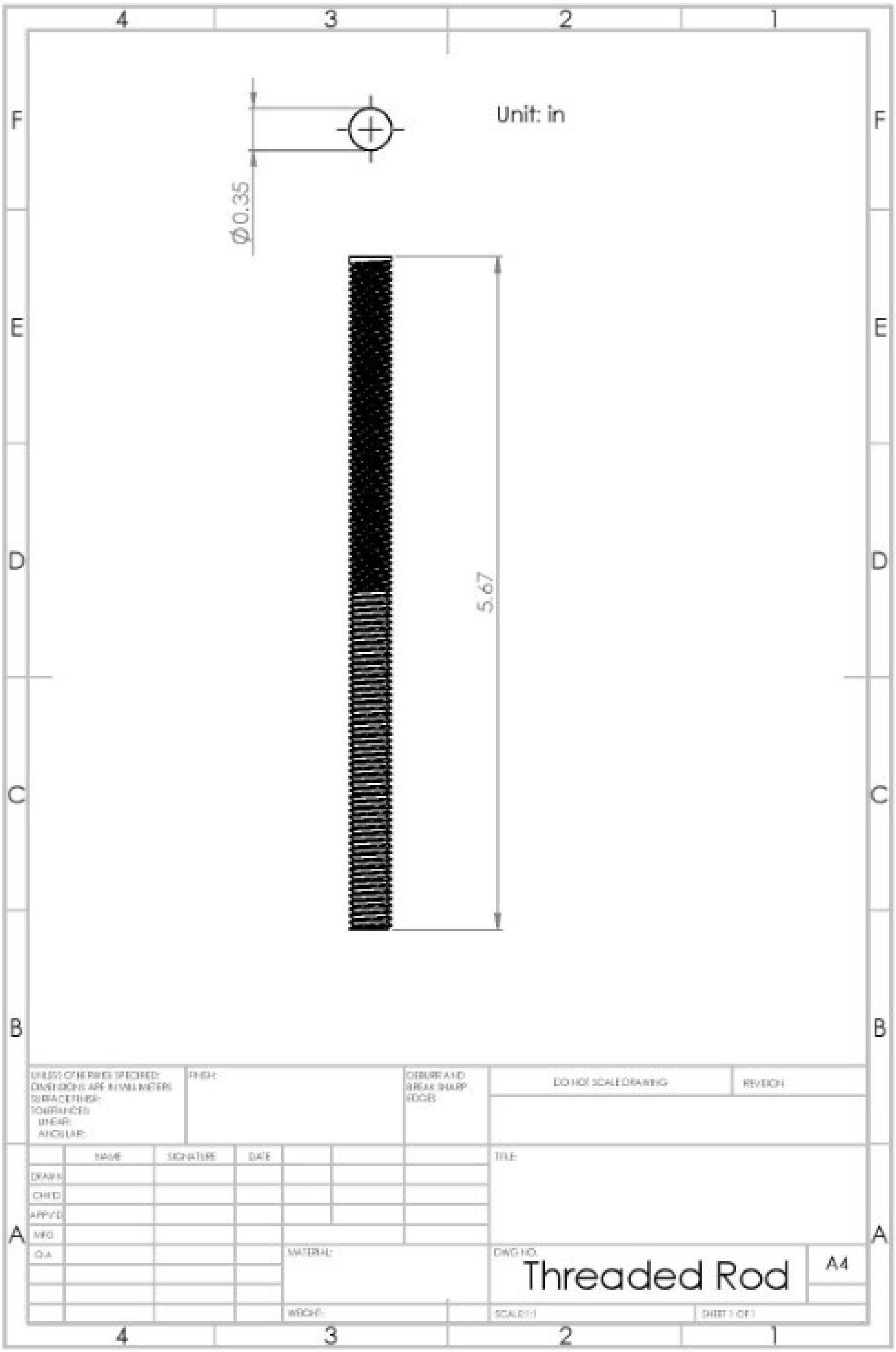

Figure 13 Threaded rod drawing

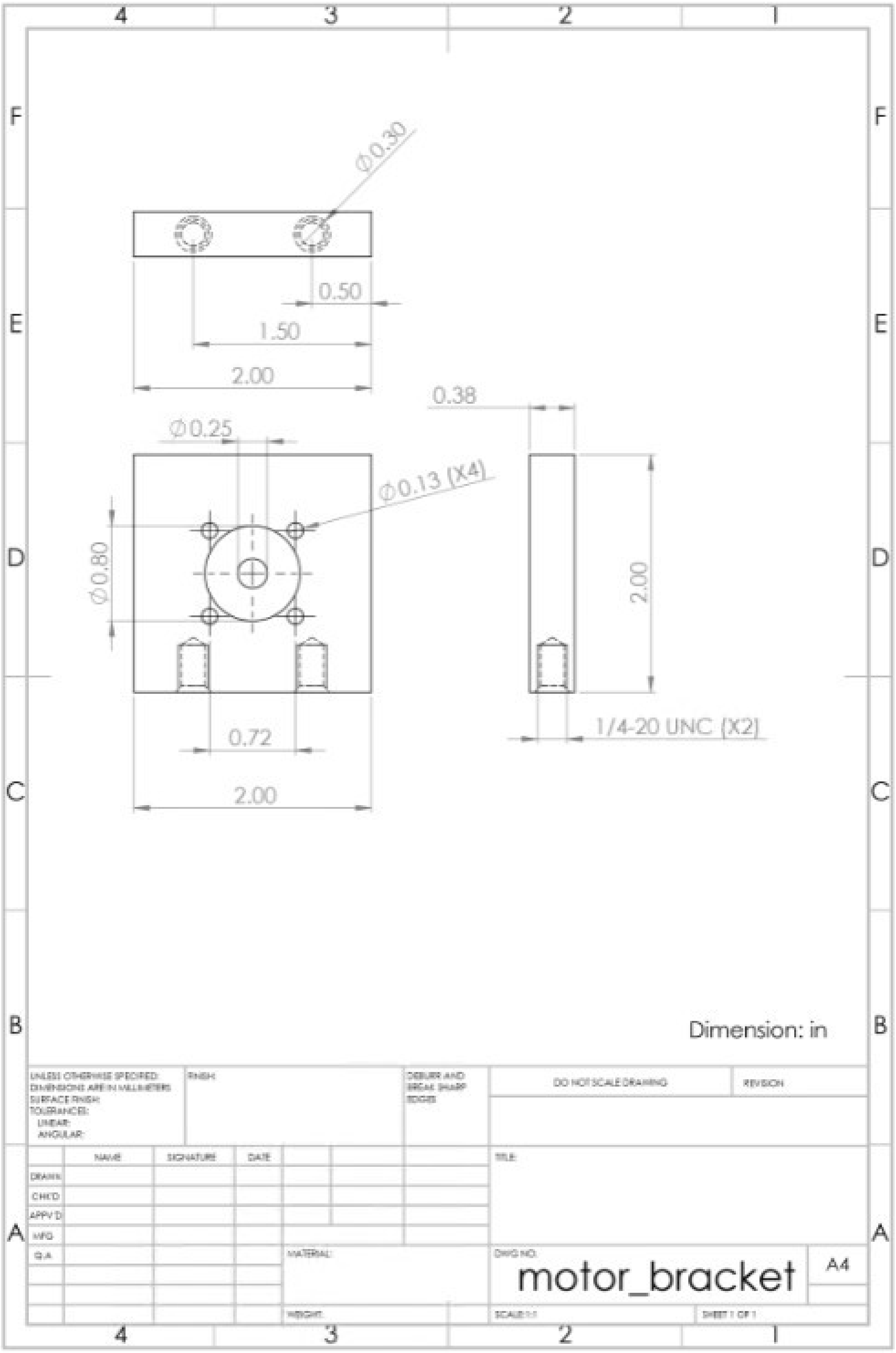

Figure 14 Motor mounting cross-sectional drawing

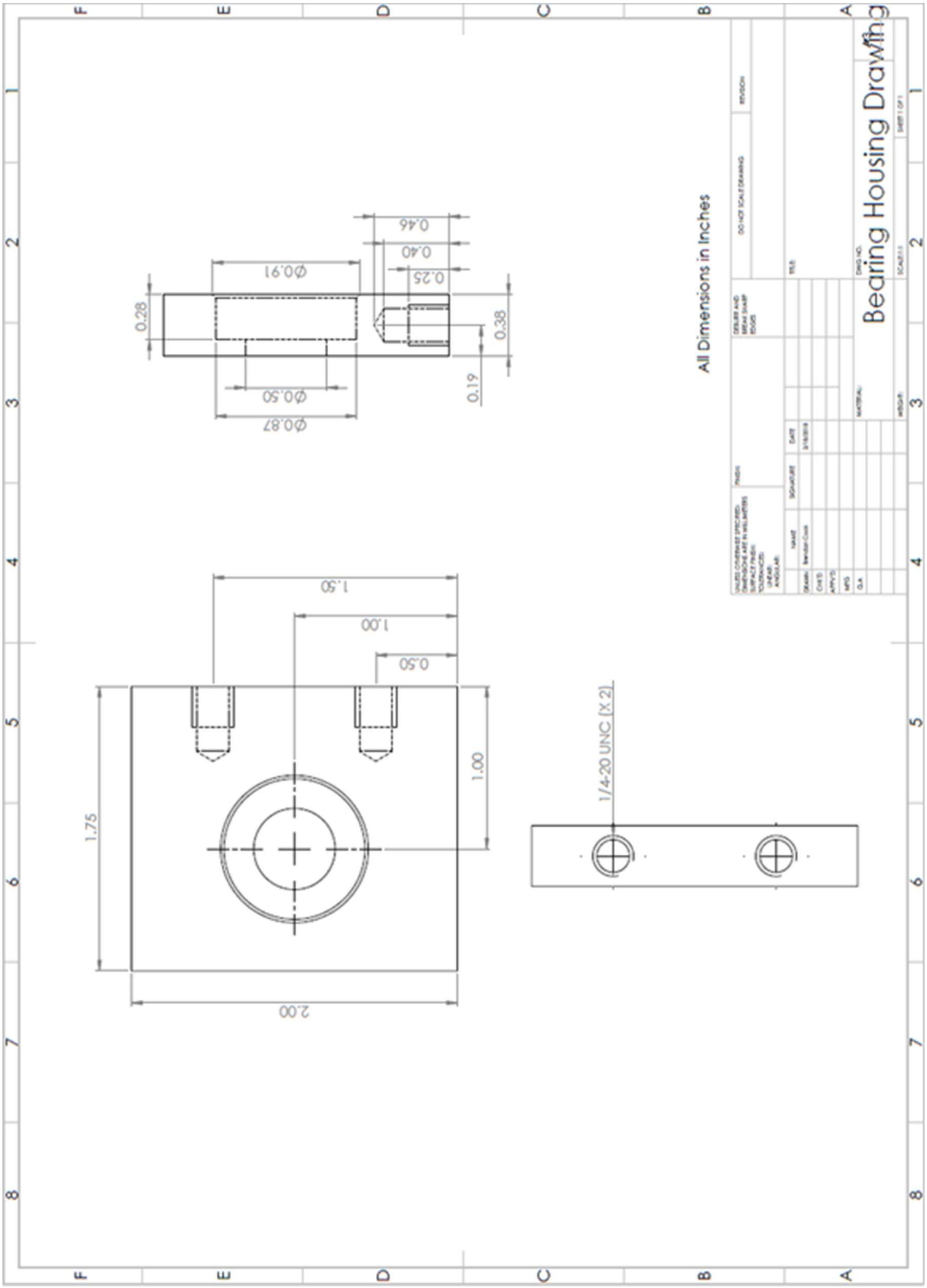

Figure 15 Bearing housing cross-sectional drawing.

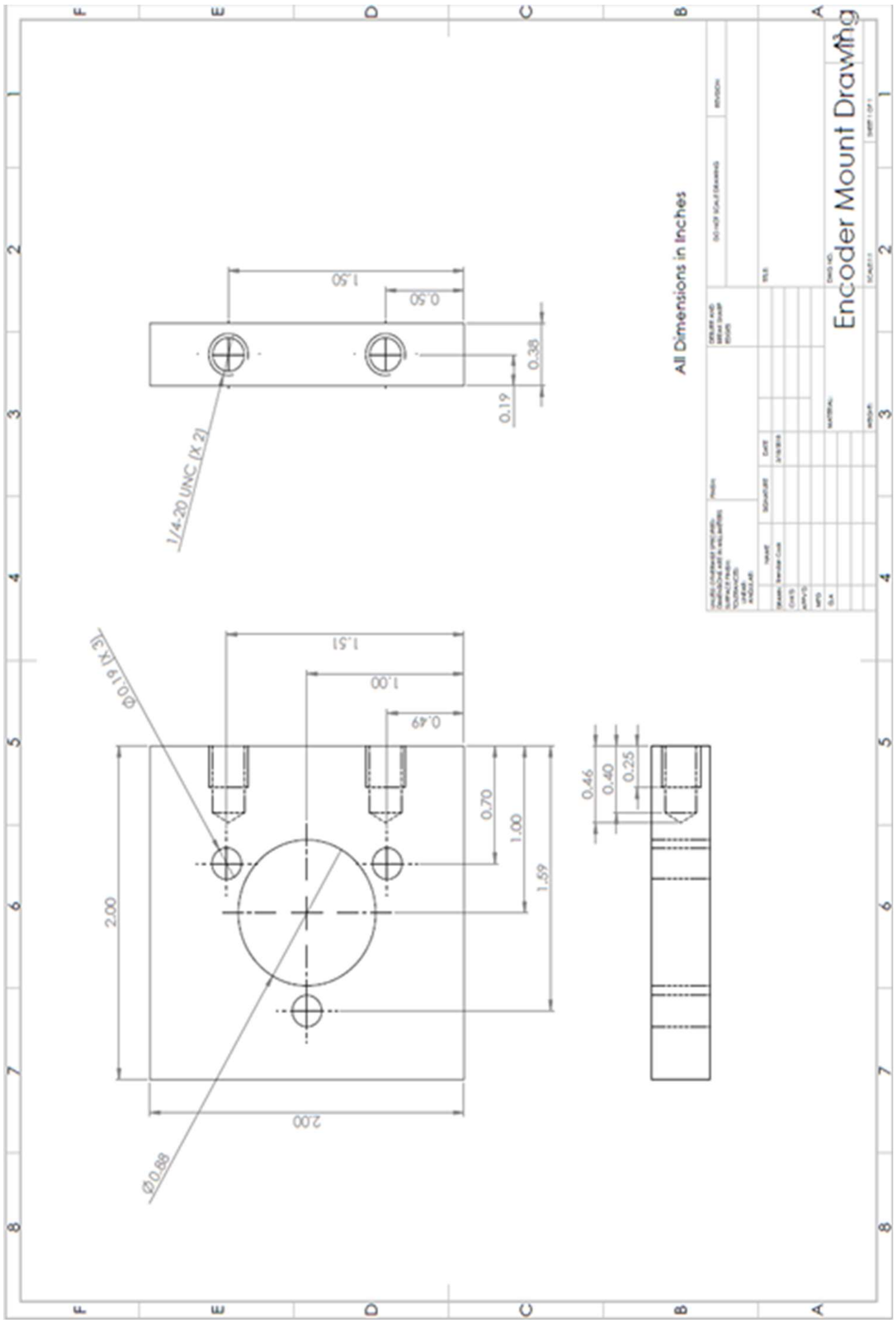

Figure 16 Encoder mounting cross-sectional drawing.

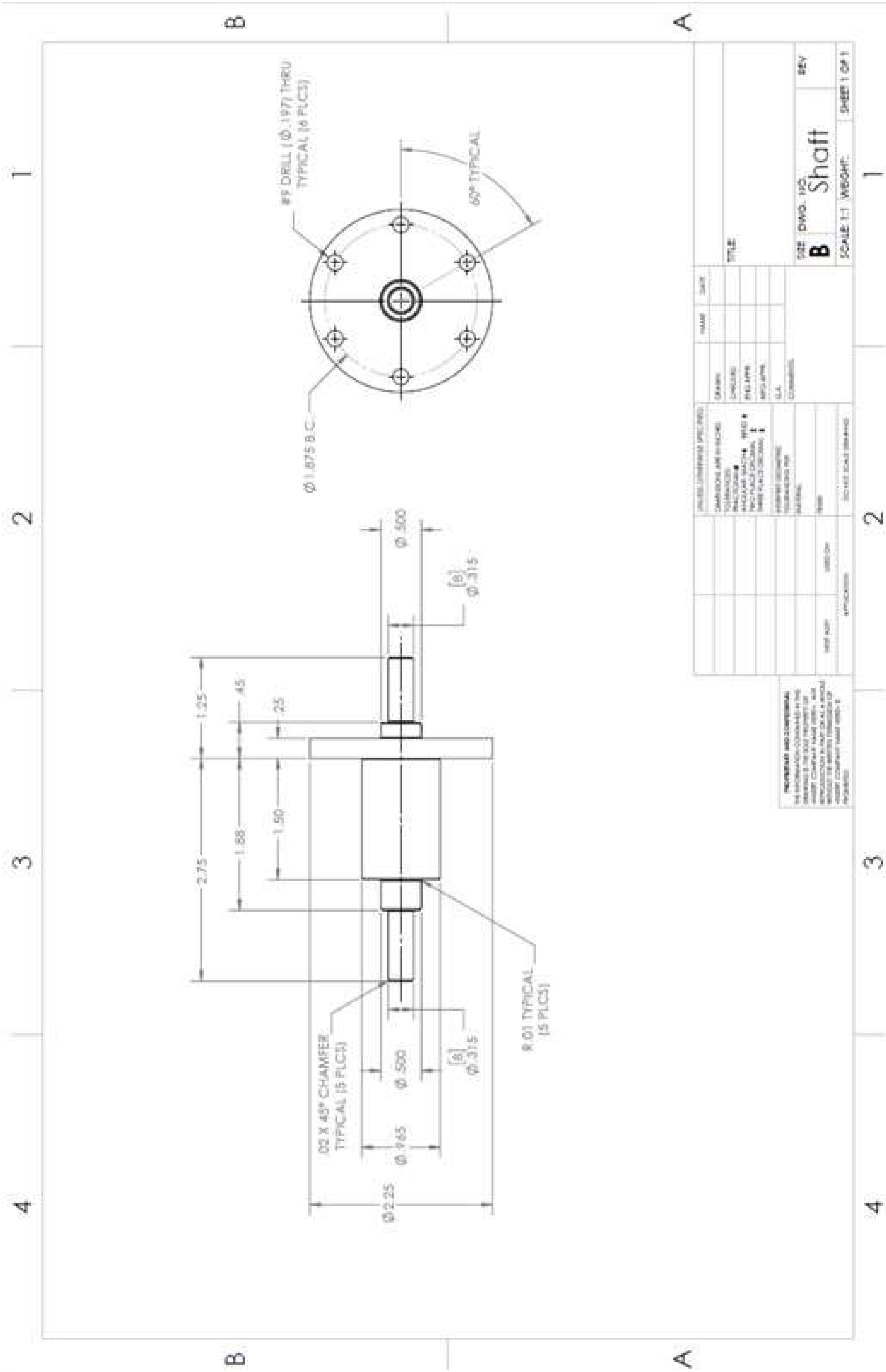

Figure 17 Drive shaft cross-sectional drawing

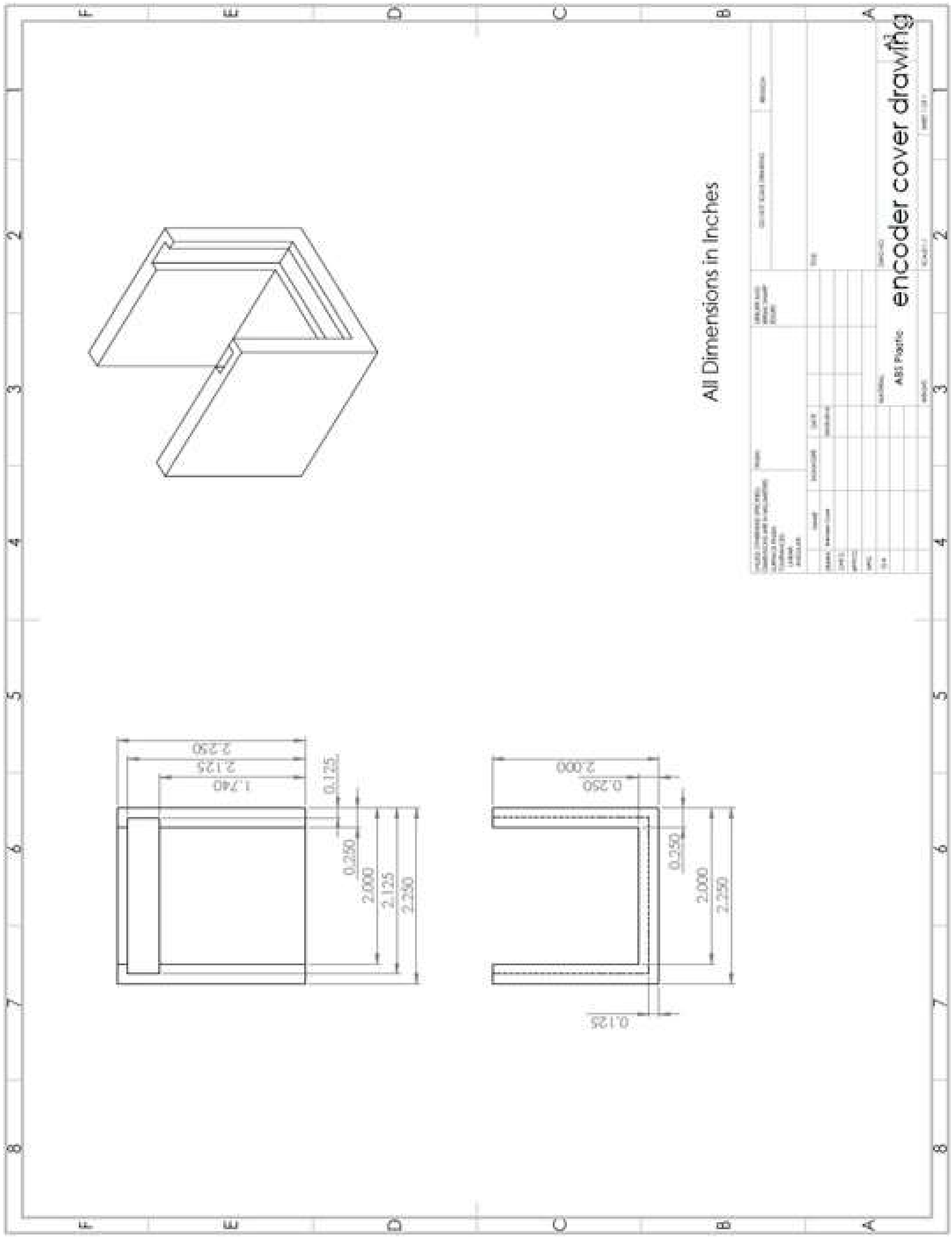

Figure 18 Encoder housing cross-sectional diagram

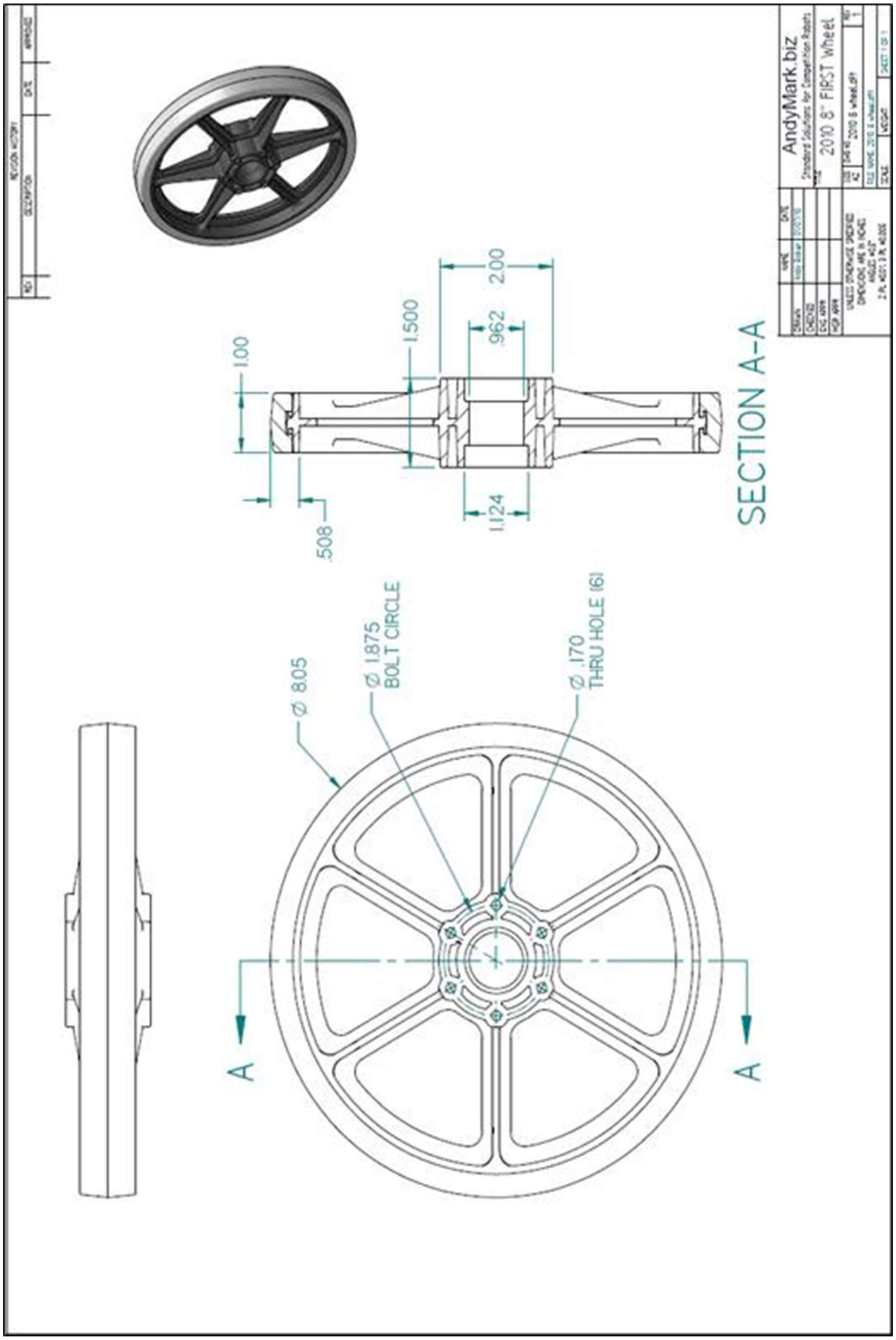

Figure 19 8" plastic wheel cross-sectional drawing

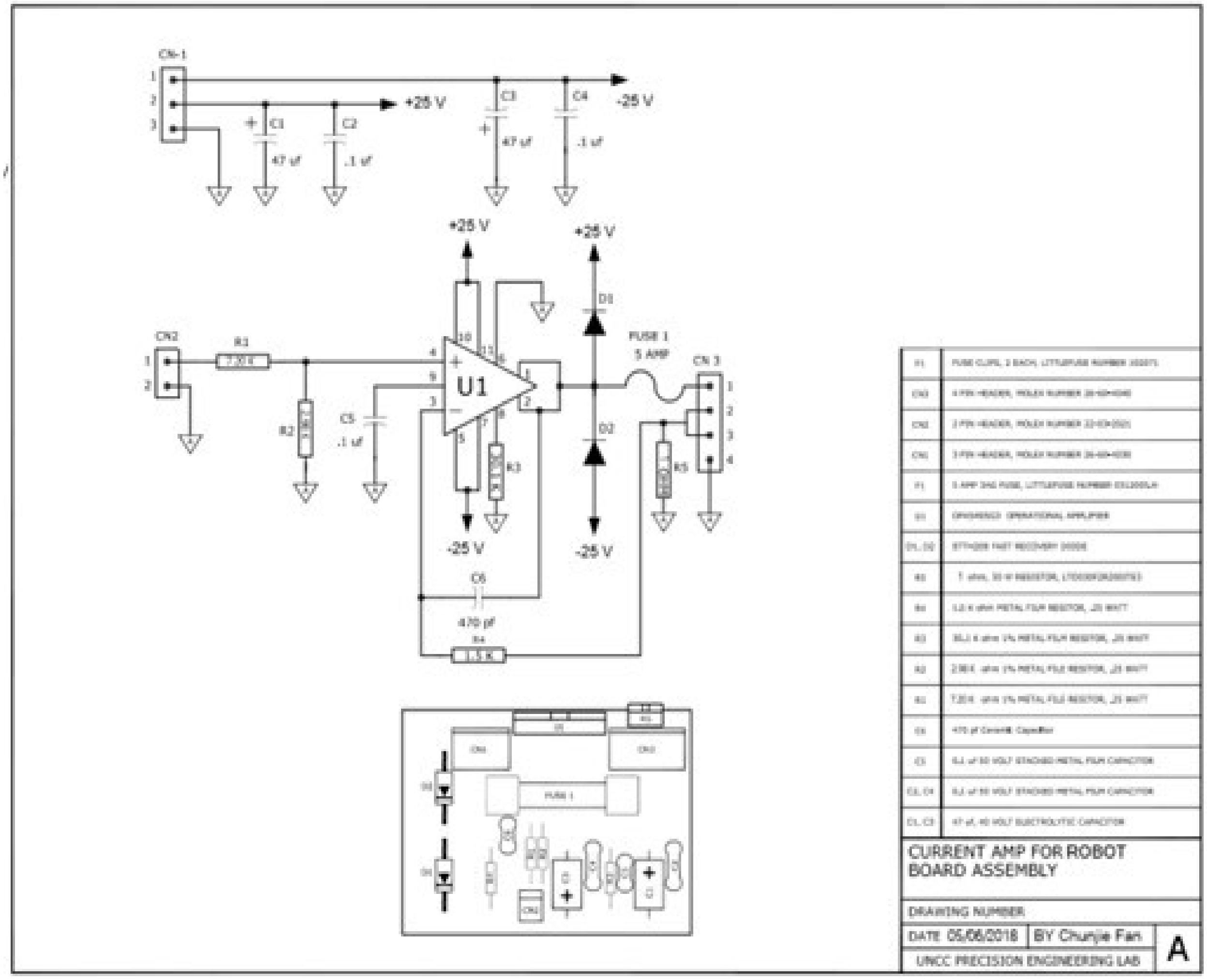

Figure 20 Old amplifier circuit diagram