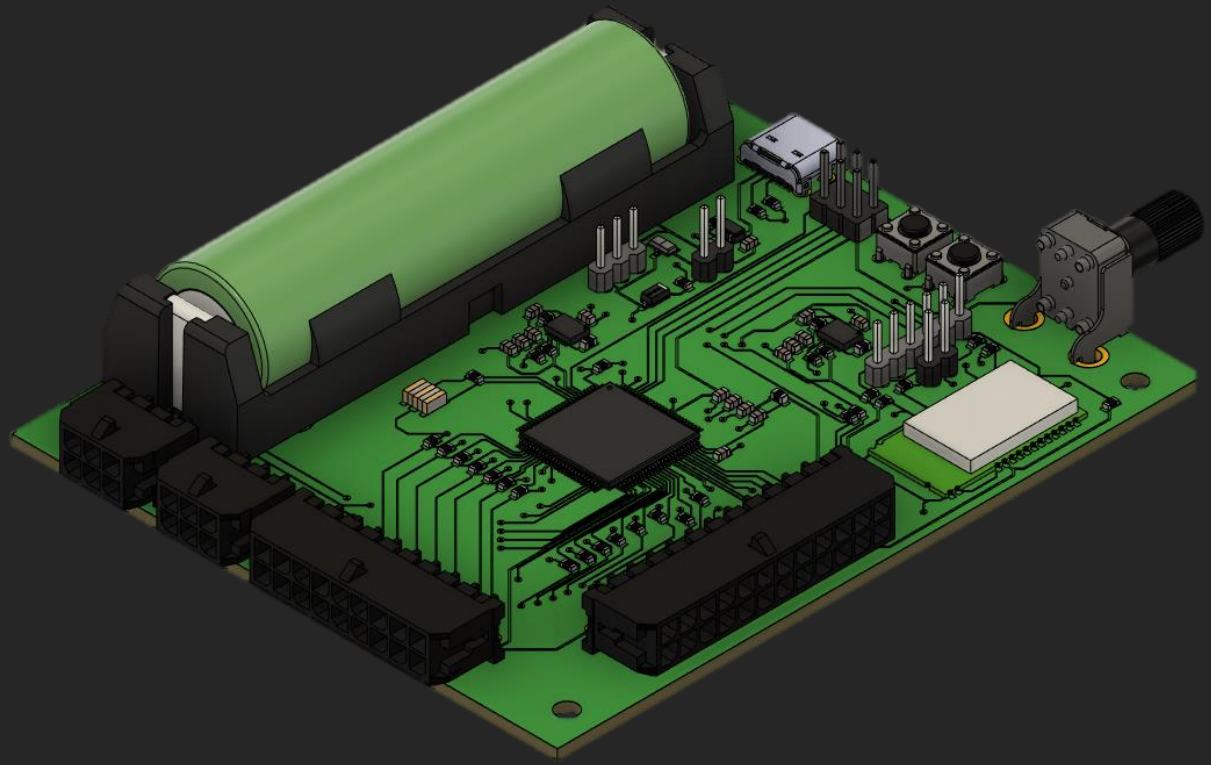
Helicopter Collective Control for Flight Simulators



Group 20 – 7/26/2021

Meet the Team

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B.S. Computer Engineering

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Picture Omitted

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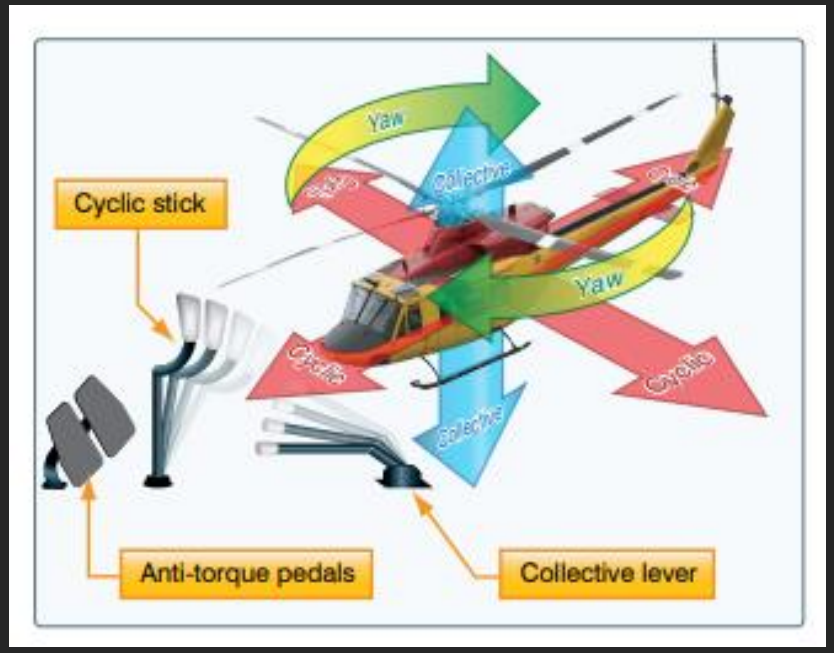
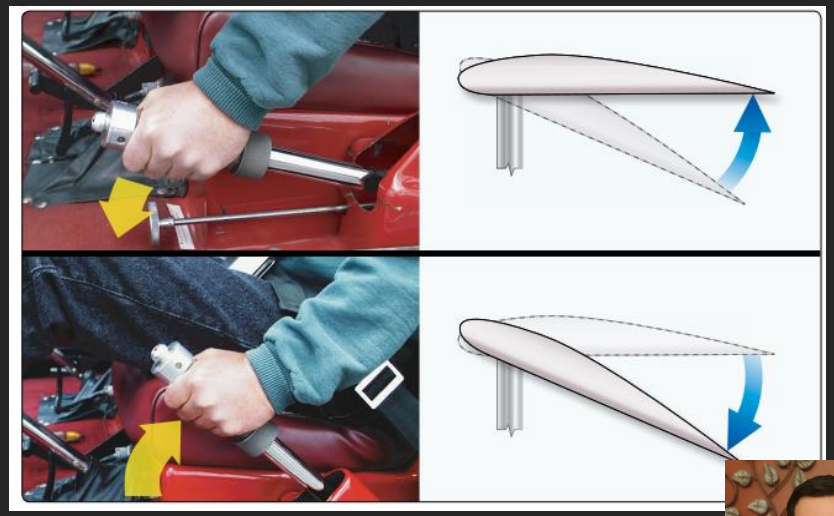
Helicopter Collective Control

- Three main helicopter controls
  - Pedals control direction which the nose points (yaw)
  - Cyclic controls movement in horizontal axis
  - Collective Control consists of throttle and lever
    - Throttle controls engine power/rotor speed
    - Lever controls movement in vertical axis
      - Changes angle of all main rotor blades simultaneously
      - Affects amount of lift generated by the blades





Motivation

- Consumer flight simulation products tailored toward airplane controls
  - More familiar to the average user of flight simulation software
  - Results in a relative lack of options for flight simulation equipment for more niche flight controls such as a helicopter collective
- Current options for helicopter-specific flight simulation controls tend to be rather expensive, often thousands of dollars

Goals and Objectives

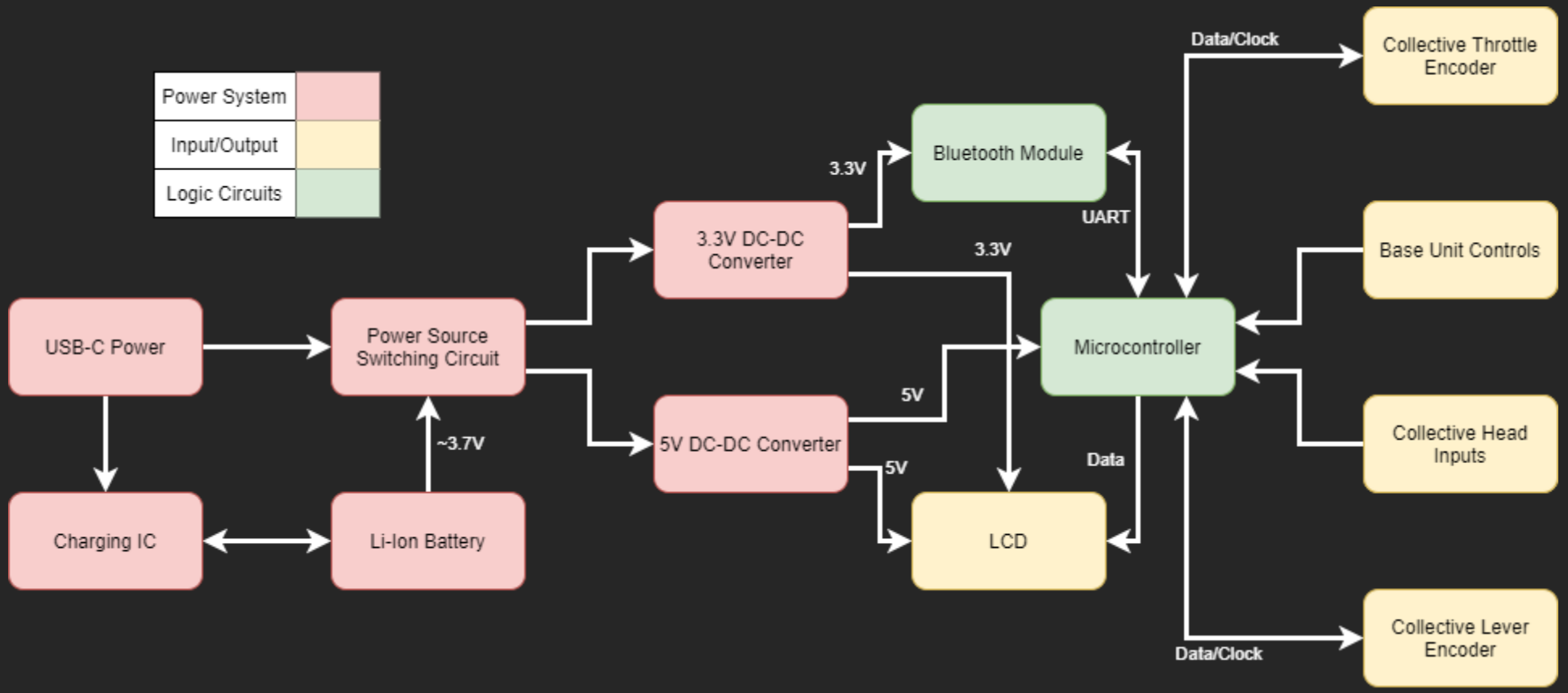
- Relatively low cost
  - Extensive use of 3D printing for mechanical structure
- Portable
  - Simple bracket mounting system, rechargeable battery power, wireless Bluetooth communication
- Accurate
  - High resolution absolute rotary encoders to measure angular position of physical parts
- Modular
  - Include a way to easily swap out collective heads to represent different helicopters

Specifications

1	Cost	< $500
2	Weight	< 20 lbs.
3	Line of Sight Wireless Connection Range	≥ 15 ft
4	Idle Runtime (Wireless)	> 10 hours
5	Collective Base Size	< 1 cu. ft
6	Minimum Measurable Change of Lever Angle	< 1°
7	Angular Variance at Idle	±5% of total angular travel
8	Number of Unique Collective Heads	≥ 2 Heads
9	Angular Poll Rate	≥ 3 Hz
10	Collective Lever Angular Travel Range	≥ 30°
11	Calibrated Digital Output Range	Min: 0, Max: 1023
12	Operating System Compatibility	Windows 10

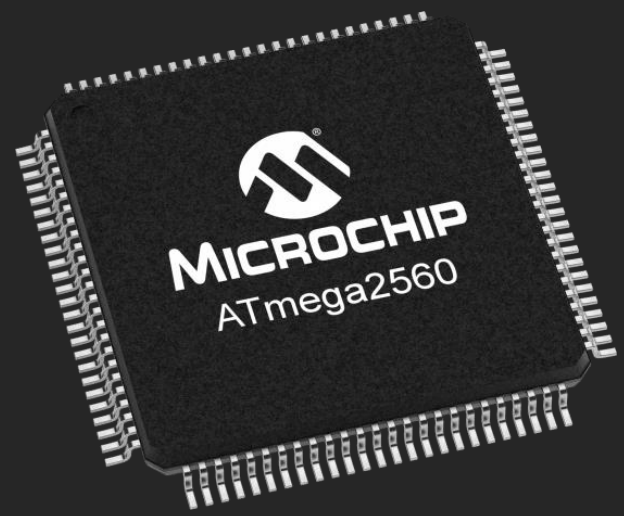
Electrical Hardware Design

Hardware Block Diagram



ATmega2560 Microcontroller

- 16 MHz clock allows for seemingly instantaneous response to user input
- 86 GPIO pins accommodates large number of inputs
  - Collective head and top panel require significant number of GPIO pins
  - Number of inputs varies per head
- 4KB EEPROM allows for persistent calibration data
- UART capability required to interface with Bluetooth Module
- Available on Arduino Mega 2560 development board for effective prototyping and development



Clock Speed	16 MHz
Memory & Storage	256KB Flash, 4KB EEPROM, 8KB SRAM
Number of GPIO Pins	86 (digital, analog, and USART/I2C capable)

Human Interface Devices (HIDs)

- Human Interface Devices (HIDs) are a class of devices which adhere to the USB HID definition
  - HID definition describes the protocol for input/output devices to interface with a host device
  - Most common computer peripherals are an HID (mouse, keyboard, game controller, etc.)
- HID over GATT is a profile established by the Bluetooth SIG which defines how to implement HID via Bluetooth Low Energy
  - HID over GATT is essential as it converts raw data sent from the collective into inputs which are interpreted as gamepad inputs by the host computer
- Helicopter simulation software almost universally has support for generic HID devices
  - The collective will send data representing two axes as well as a collection of buttons, which are then mapped in the simulation software to their corresponding actions

BM70 Bluetooth Module

- Fully Integrated Bluetooth Software Stack
  - Bluetooth Low Energy capability reduces power consumption
  - Bluetooth 5 is most modern specification
  - Full control over Bluetooth stack allows for HID implementation
- Integrated antenna and shield provides drop-in Bluetooth functionality
  - No need for externally connected or PCB mounted antenna
  - Factory design is shielded and certified in a variety of markets
- UART Interface allows for easy microcontroller connection
  - After configuring Bluetooth module, simple byte commands can be passed over UART between ATmega2560 and BM70 to facilitate Bluetooth communication
- Manufacturer provided software allows for ease of configuration and testing

Bluetooth Version	5.0
Wireless Range	50m
Software Interface	UART

EMS22A50 Rotary Encoder

- 1024 positions across 360 degrees of travel
  - 1024 positions provides accuracy of 0.35 degrees per step
- Absolute style encoder maintains position across power cycles
  - Magnetic mechanism increases lifespan and feel as compared to physical mechanism
- Panel mount allows for simple integration into mechanical design

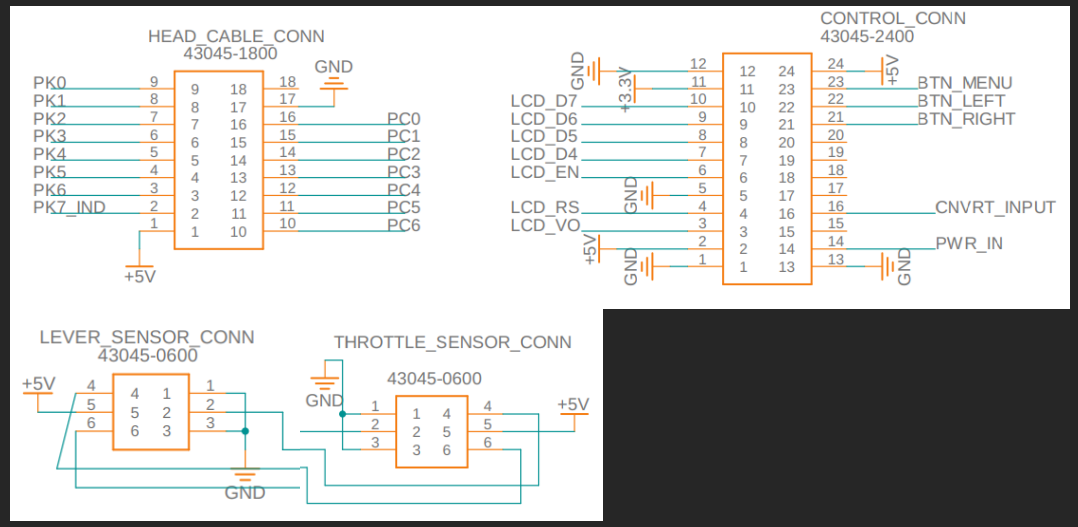
Resolution	1024 positions
Accuracy (nominal)	+/- 0.7 degrees
Mounting Style	Panel Mount
Encoder Style	Absolute (magnetic)
Rotation	360 degrees, continuous

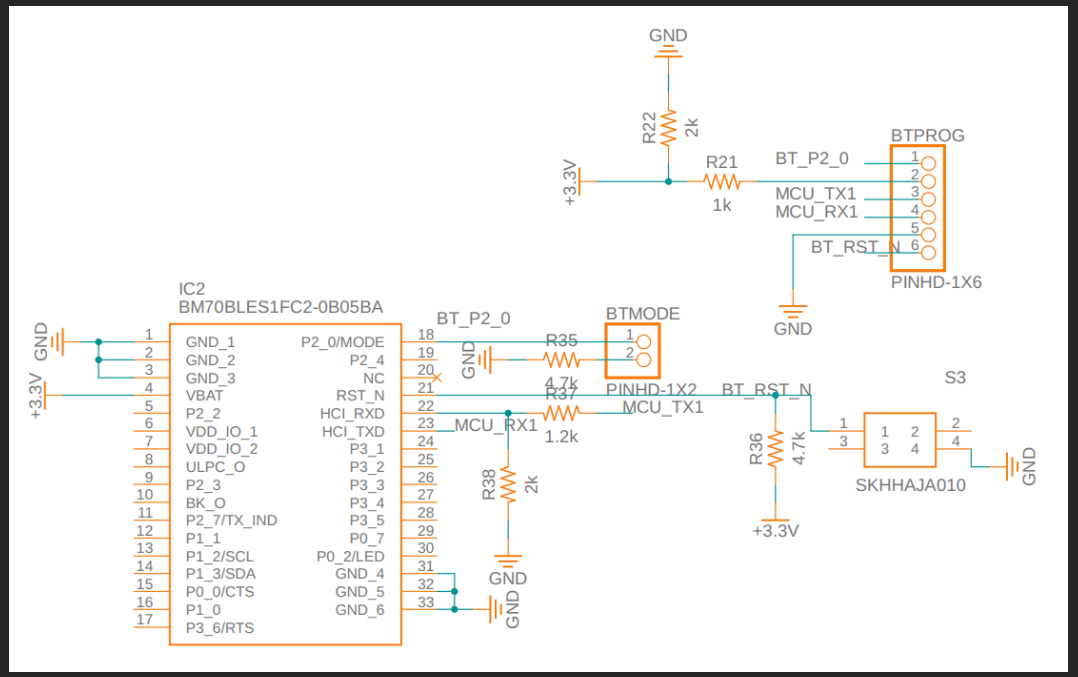
Molex Connectors

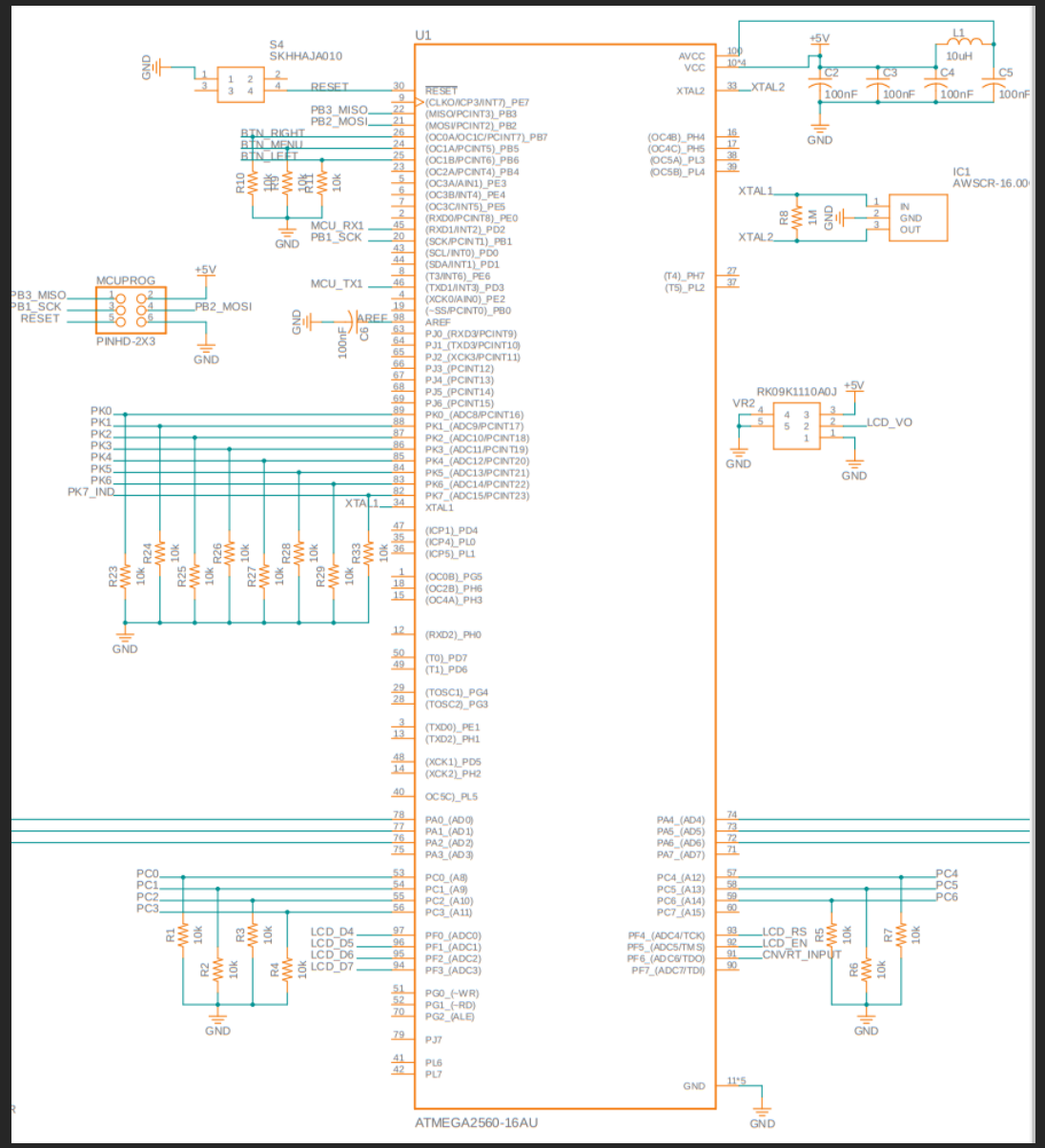
- Molex connectors allow for ease of assembly and cable management
  - Provide a more professional product feel
  - 17 pin Molex connector facilitates the quick-detach head mechanism
- Variety of mounting styles allow for flexible usage
  - 17 pin Molex connector is panel mounted and can be integrated directly into the collective lever
  - 6, 18, and 24 pin connectors are PCB mounted to connect top panel, head inputs, and encoders

Mounting Style	PCB Mount & Panel Mount
Number of Pins	6, 17, 18, 24
Attachment Style	Friction, clip

Electrical Hardware Schematics

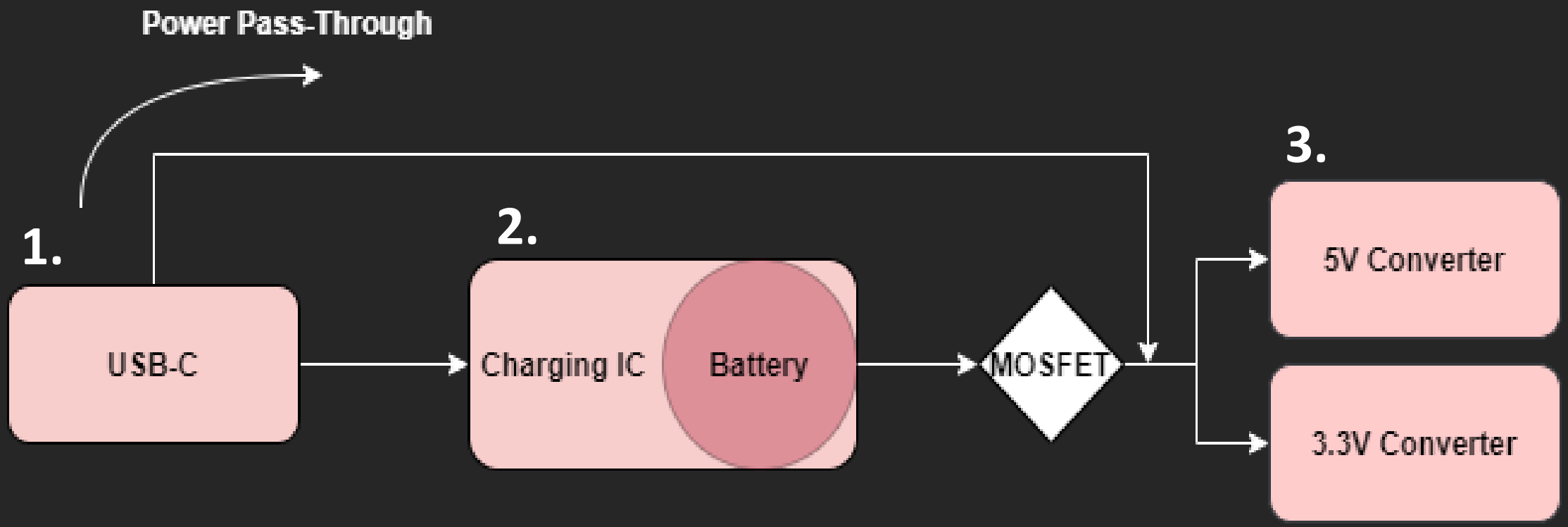






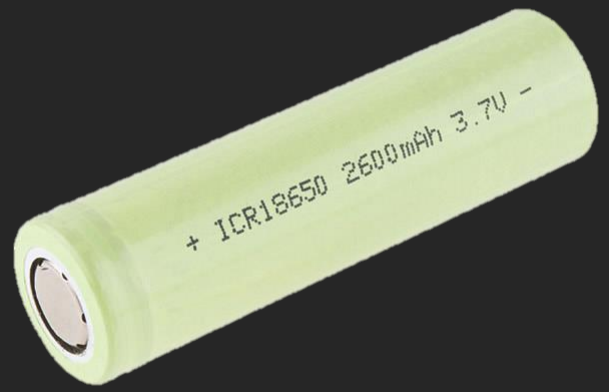
Power Design

Power System



18650 Li-Ion Battery

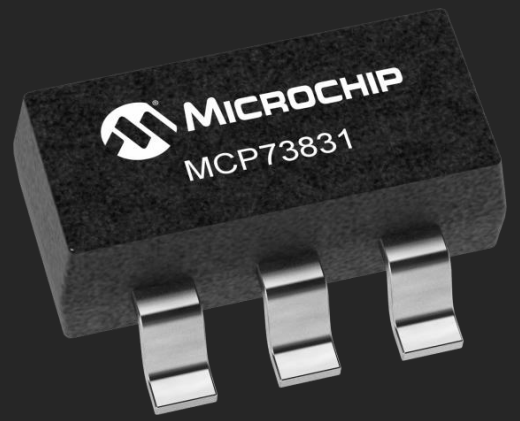
- Rechargeable Battery suitable for portable applications
- Benefits of 18650 Li-Ion batteries include:
  - Long Life-Cycles
  - High Energy Density
  - Wide availability
  - Low cost



Nominal Voltage	3.6V
Voltage Range	2.5V – 4.2V
Capacity Range	~2300-4000 mAh

MCP73831 Charging IC

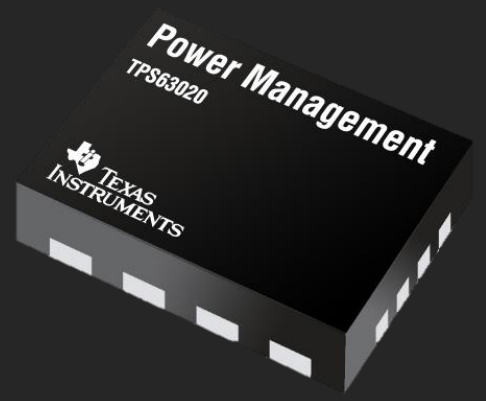
- Small, affordable, and low number of external components required
- Maximum voltage charge of 4.2V, which is maintains a safe limit for the battery
- Suitable input voltage range and programmable output charging current range, considering voltage and current requirements for battery and system.
- Safety Features Considered
  - Charge Termination
  - Thermal Regulation



Max. Charge Voltage	4.2V
Input Voltage Range	3.75V – 6V
Programmable Charging Current Range	15mA – 500mA
Charge Termination	7.5% of programmed charge current
Thermal Regulation	Shut-off at 150°C

TPS63020
Buck-Boost Converter

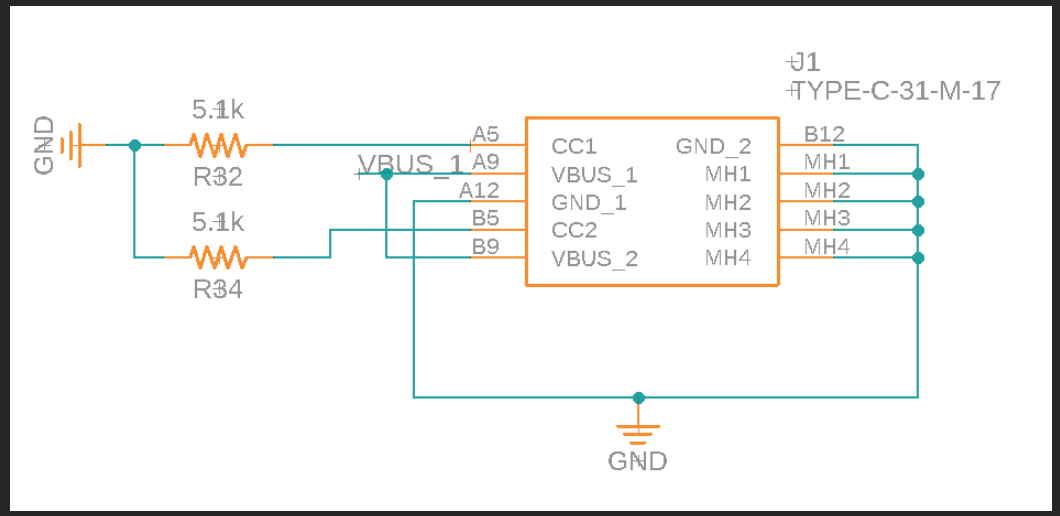
- Buck & Boost Converter allows flexibility in stepping-up and stepping-down voltage
- Promising input voltage range which will ensure required voltage outputs even at very low voltage levels
- Suitable programmable output voltage range that satisfies project requirements
  - Output voltage programmed using simple voltage divider
- Supports up to 4A of output current, which is more than enough for our project



Input Voltage Range	1.8V – 5.5V
Selectable Output Voltage Range	1.2V – 5.5V
Max. Output Current	4A

USB-C

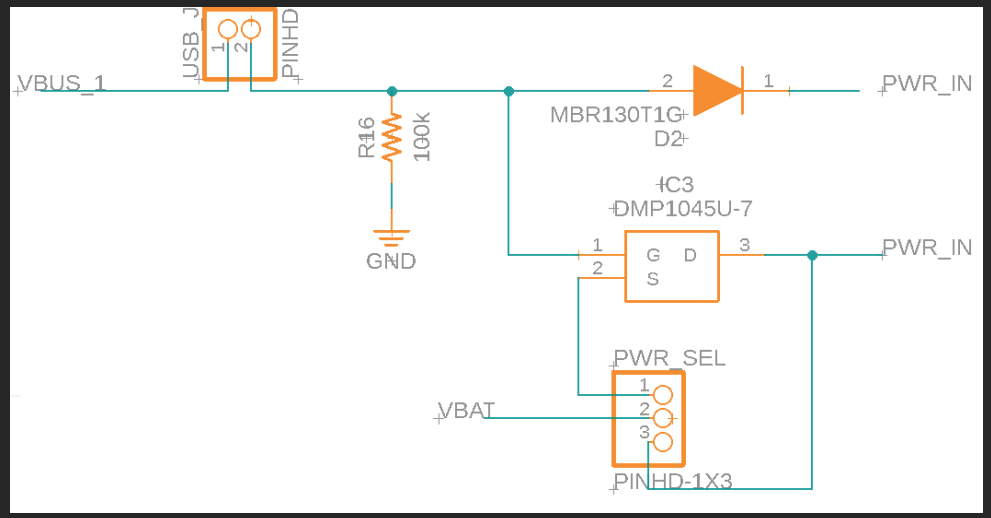
- Popular design and advanced technology
  - Fast charging
  - High power capabilities
  - Supports USB-PD
  - Ubiquitous in modern devices



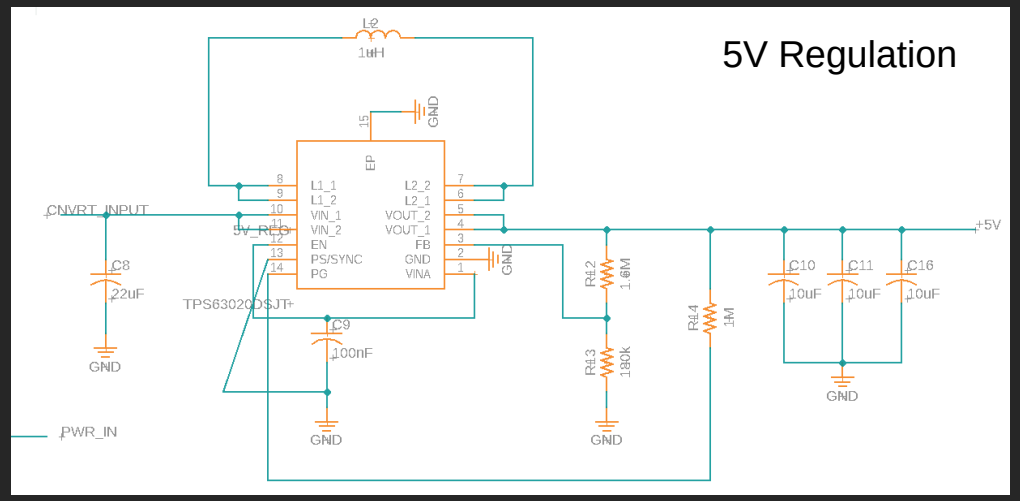
Design	Reversible
Voltage	5V
Max. Current	3A
Supports USB-PD for higher power options	Max:100W

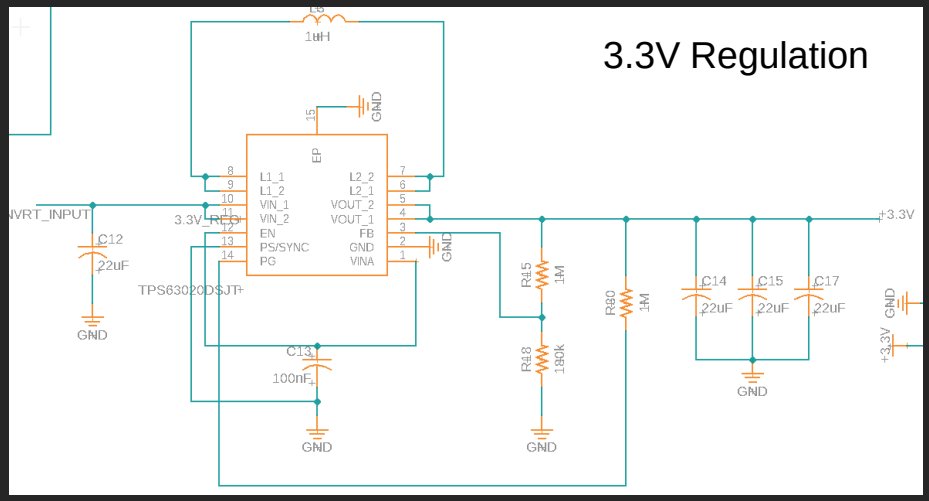
Power Passthrough

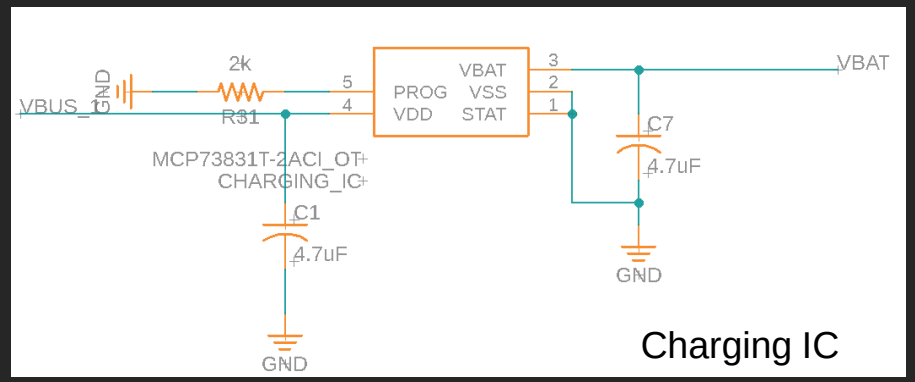
- Switches system power between USB-C wired and battery
  - P-channel MOSFET detects presence of USB-C power and cuts off battery from load circuit
  - Schottky diode prevents current backflow from battery to USB-C
  - Pull-down resistor ensures battery resumes powering load circuit after USB-C power removed
- Charging IC measures charge current to determine charging progress
  - If battery is always connected to load circuit, IC never determines battery is charged
  - Load circuit and battery would split current from charging IC, resulting in slow charge

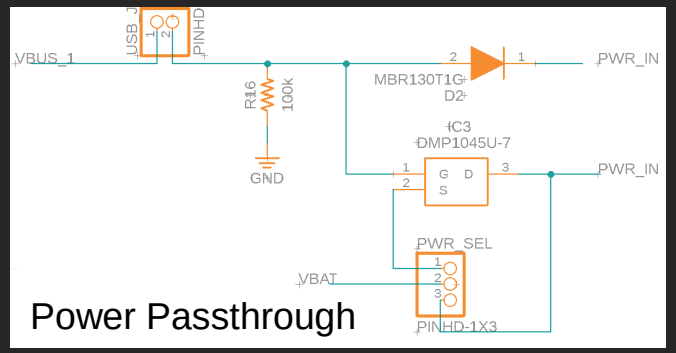


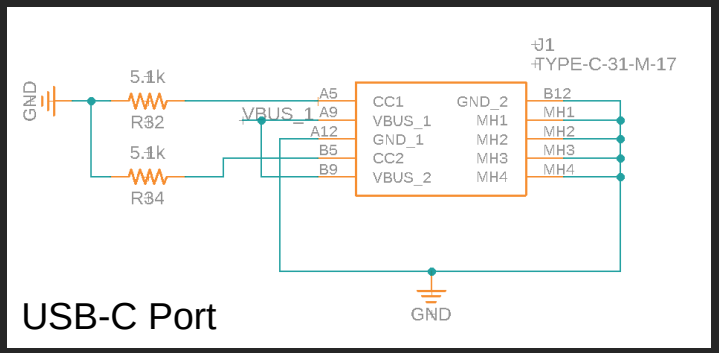
Overview of Power System



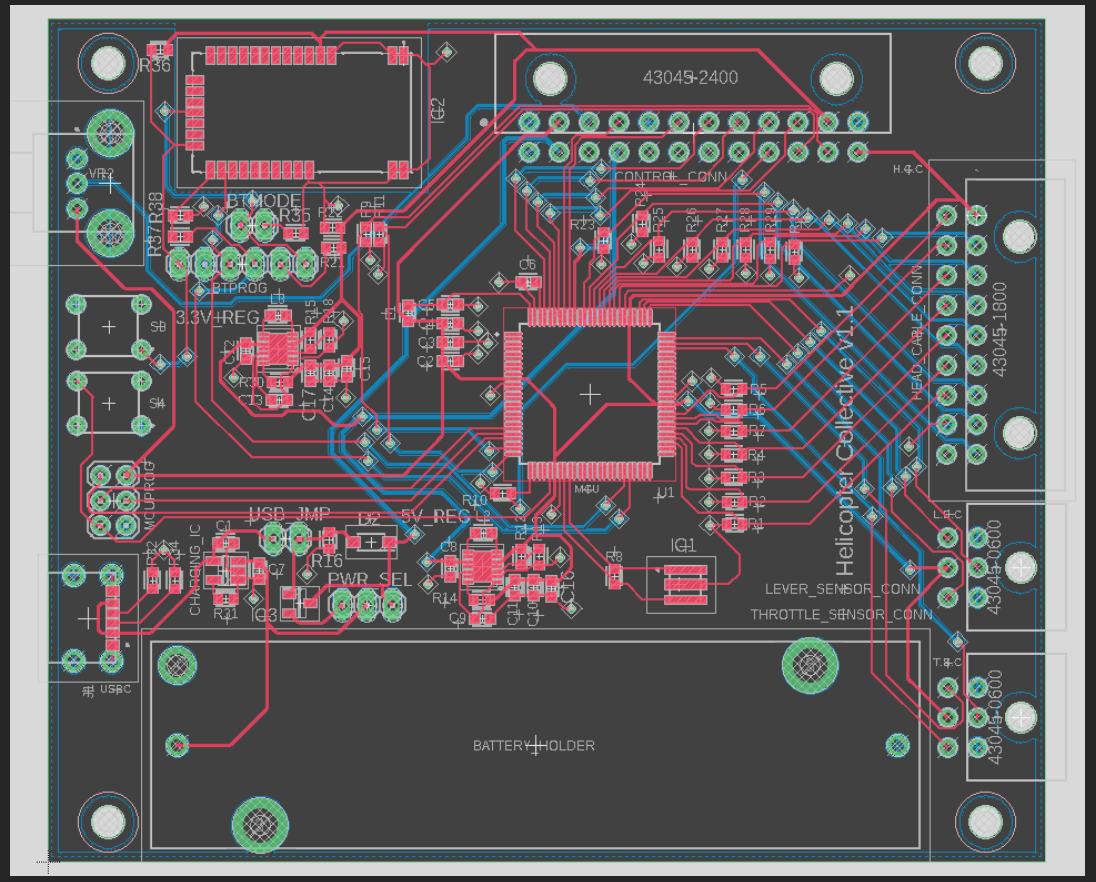




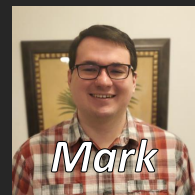




PCB Layout and Final PCB



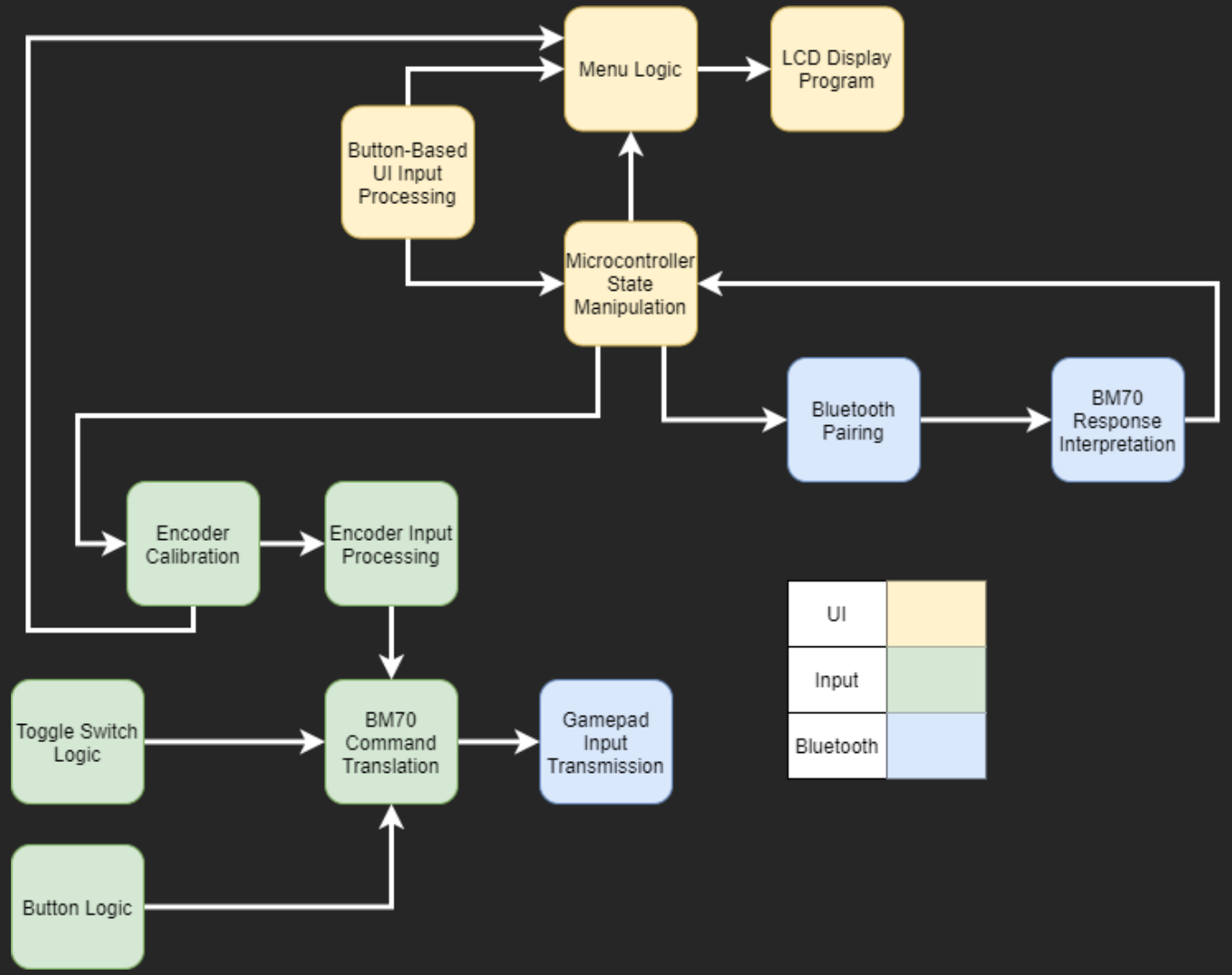
Software Design



Software Tools

- Arduino IDE
  - Programmed in a modified version of C++
  - Provides useful libraries for embedded programming
  - Allowed for programming during initial testing to easily transfer to final product
- USB-IDF HID Descriptor Tool
  - Streamlines the process of creating HID reports that adhere to HID standards
  - Report format generated via Descriptor Tool is then used when forming messages to BM70 Bluetooth module

High-Level Software Block Diagram



State-Based Menu Logic

- Software implementation on a high level implements logic that switches between various menu states
  - Bluetooth Transmission/Normal Operation
  - Encoder Calibration
  - Battery Status
  - Bluetooth Pairing
  - Bluetooth Disconnect/Remove Known Devices
- Movements between states initiated by user via buttons on collective base

Encoder Input and Calibration

- Absolute rotary encoders require specific software to take in and transmit their value
  - Data from encoder requested via specific clock signal manipulation
  - Angular position of encoder reported as value in range of 0 to 1023
  - Range of encoder encompasses full 360° range of motion, collective lever has limited range of motion
  - Calibration software implemented in calibration mode to allow user to set upper and lower bound of lever movement
    - Values taken in from the encoder from limited range of lever movement are then expanded into a range of 0-1023 to be sent over Bluetooth

Bluetooth Communication

- BM70 utilizes specific command/response format consisting of a string of bytes
  - Commands/responses are sent/received byte-by-byte over UART to the BM70
    - Commands include start advertising Bluetooth connection, send GATT characteristic value
    - Responses include pairing complete and pairing failed and are parsed by software to ensure proper connection to host computer

	HEAD		MID	DATA	CRC
	Start	**Length**	**OP Code**	**Parameter**	**Checksum**
Byte No	0	1 - 2	3	4 - xx	Length + 3
Size (Byte)	1	2	1	0	1
Value	0xAA	1	Command/ Event	Command/ Event parameter	Checksum
	SYNC WORD	Checksum to be calculated			
			TARGET LENGTH		

BM70 Command Format

Mechanical Design

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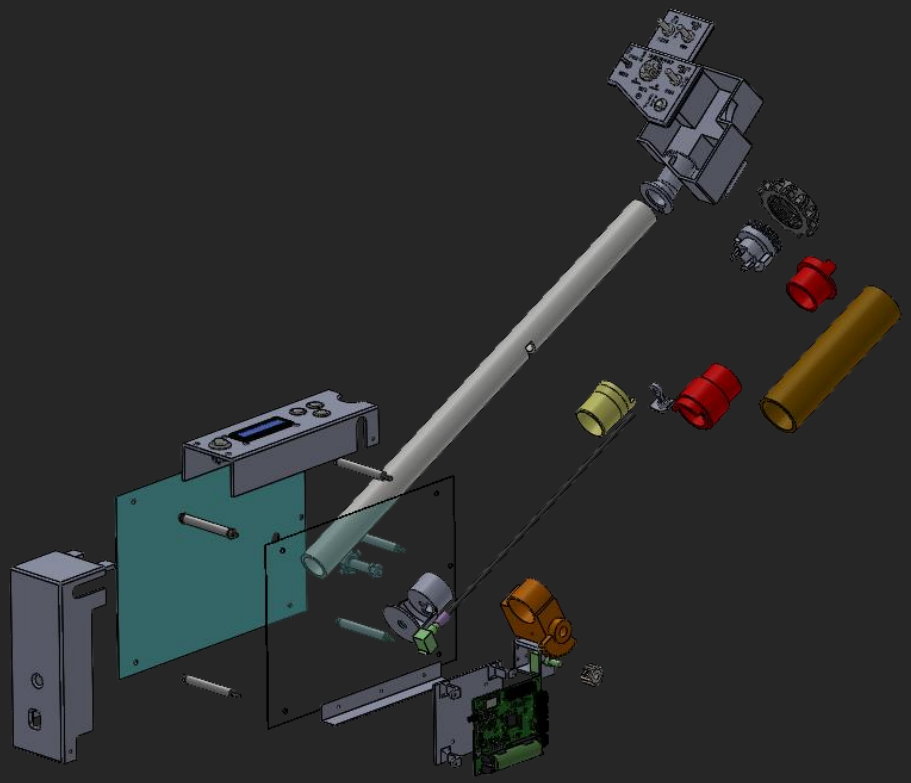
Collective Assembly



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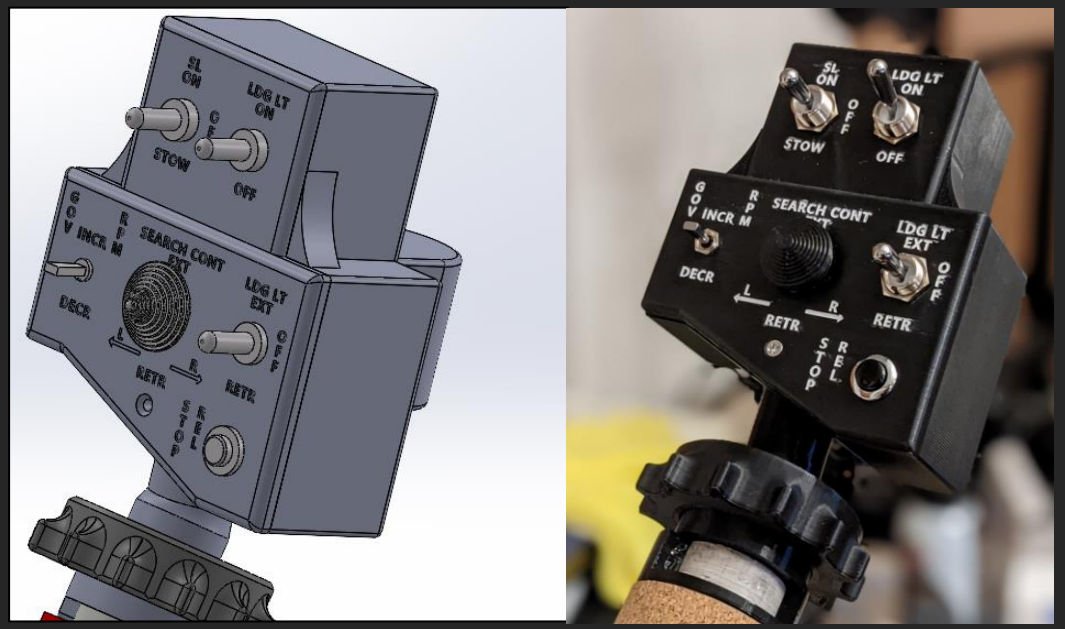
Collective Heads



Huey collective head assembly and faceplate

Bell 206 collective head assembly and faceplate

- Designed to replicate outside geometry of real collective heads based on reference images and technical manuals
  - Modifications made to aid in manufacturing and assembly

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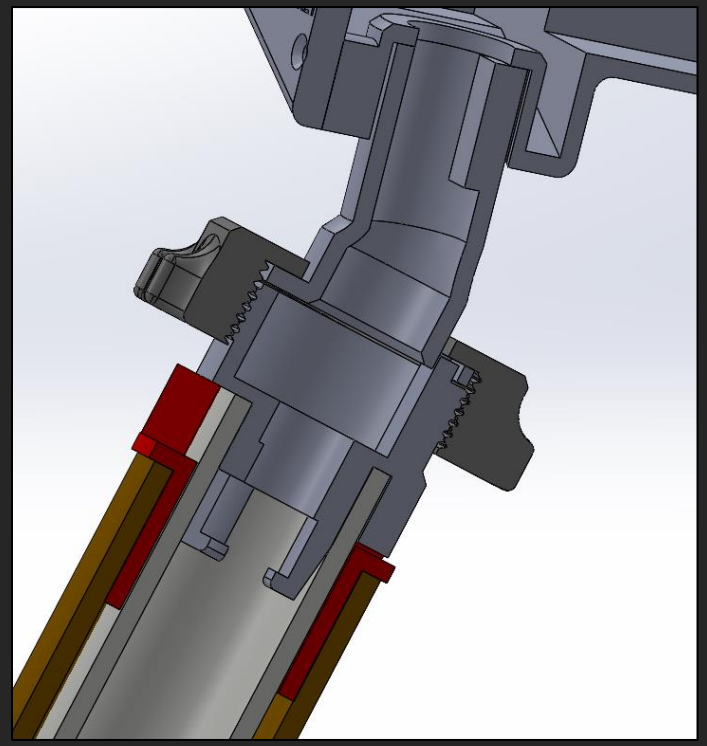
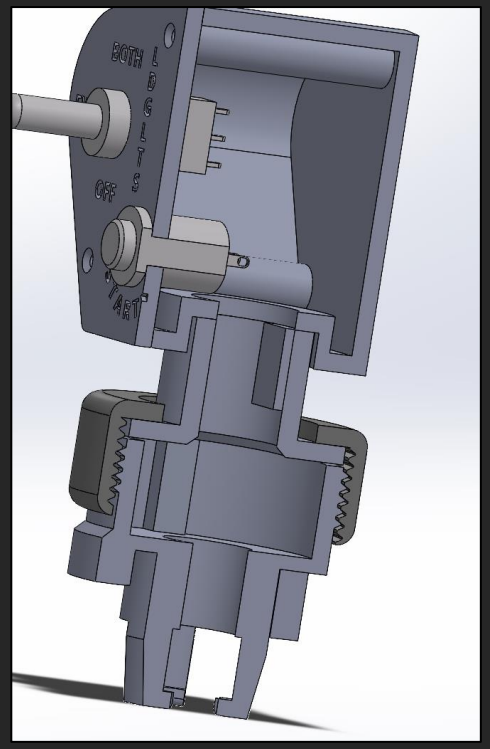
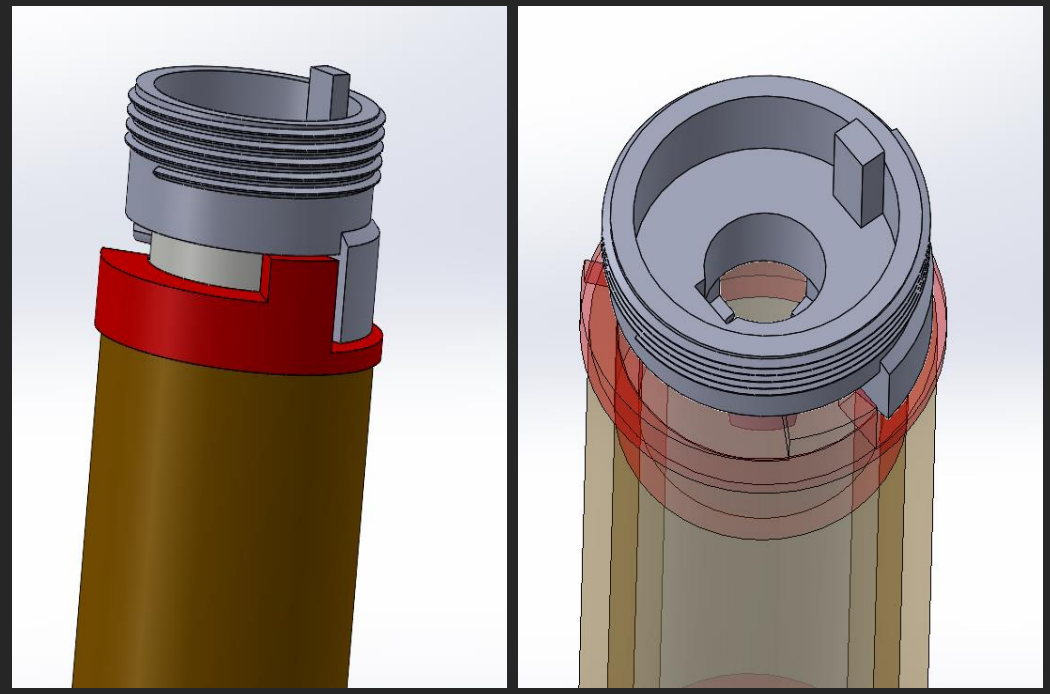
Collective Head Quick Detach



Huey head attachment method (cutaway)



Bell 206 head attachment method (cutaway)



Collective lever endcap and 17-pin Molex interface

- Design specifications require the ability to interchange collective heads
  - Solution includes throttle stop integration, 17-pin Molex connector mounting, and toolless changing of heads

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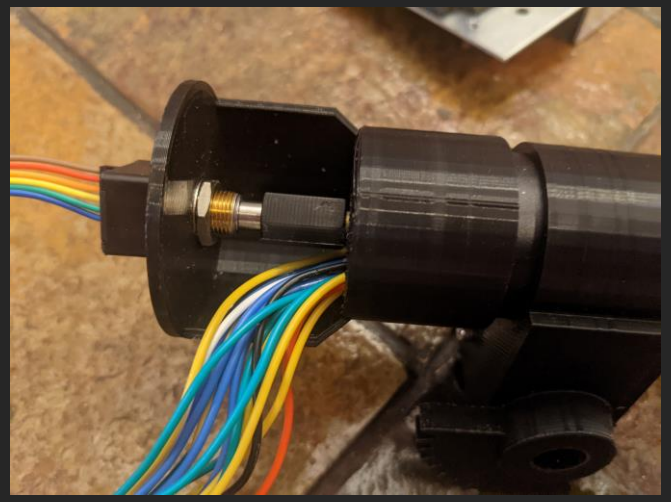
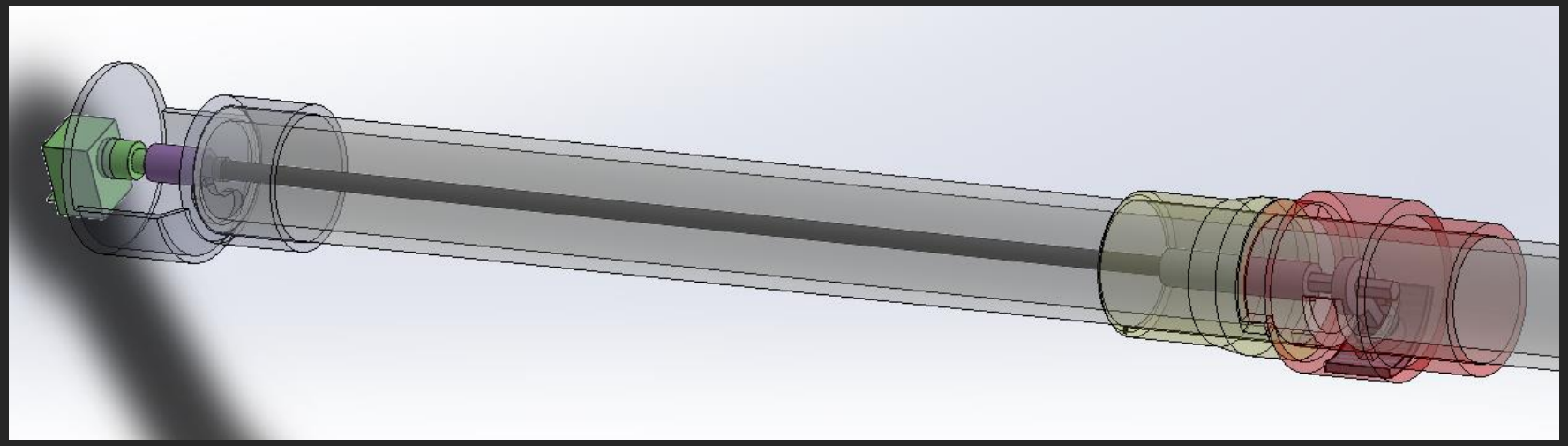
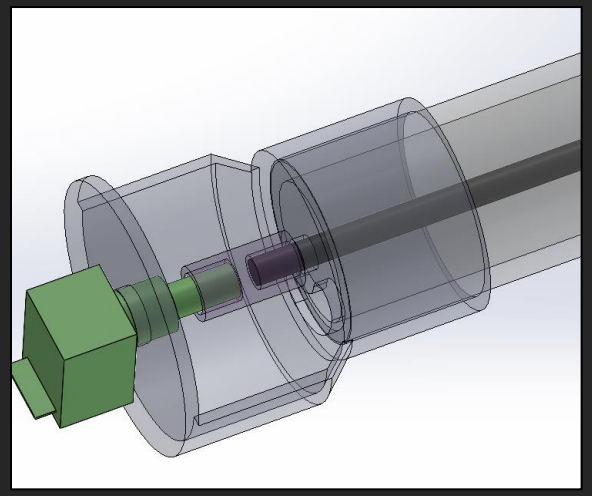
Collective Throttle



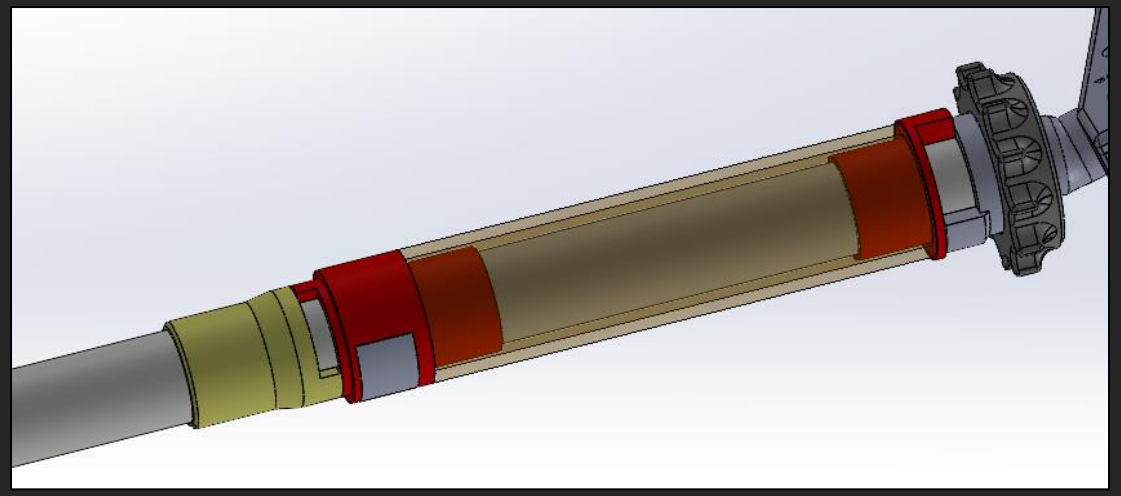
Throttle encoder housing



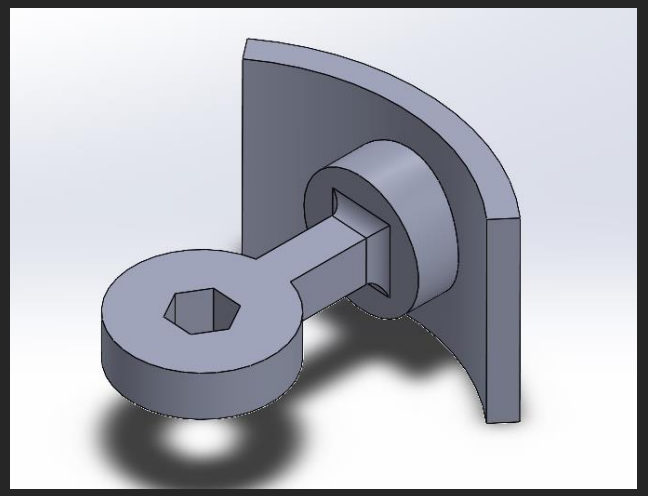
Throttle and connecting rod complete assembly



Connecting rod to encoder interface



Throttle stops for rotational limiting



Throttle to connecting rod interface

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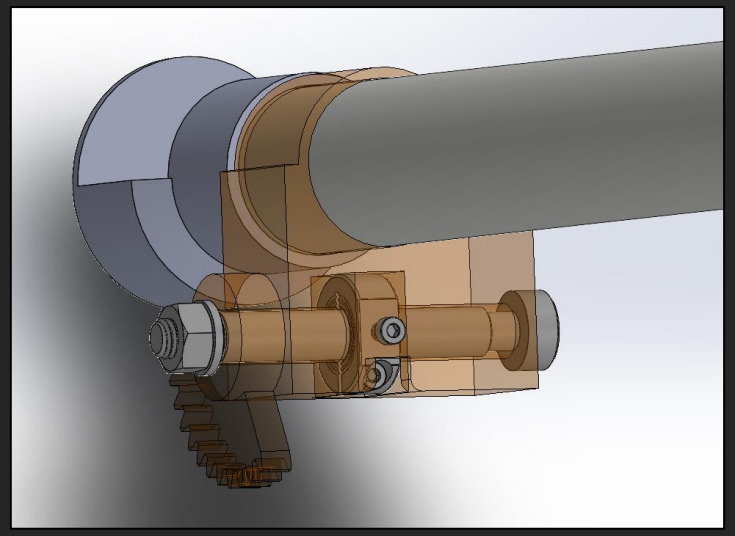
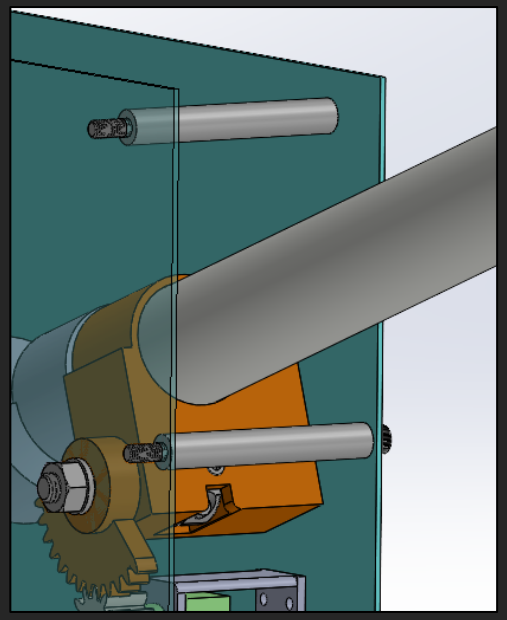
Collective Lever

Lever angle gear reduction and encoder mount



Lever pivot and friction adjustment mechanism



Lever angle travel stops

- Gear ratio: 3:1
  - Increases usable encoder steps from 128 to 384
- User can easily adjust the resistance of the collective lever

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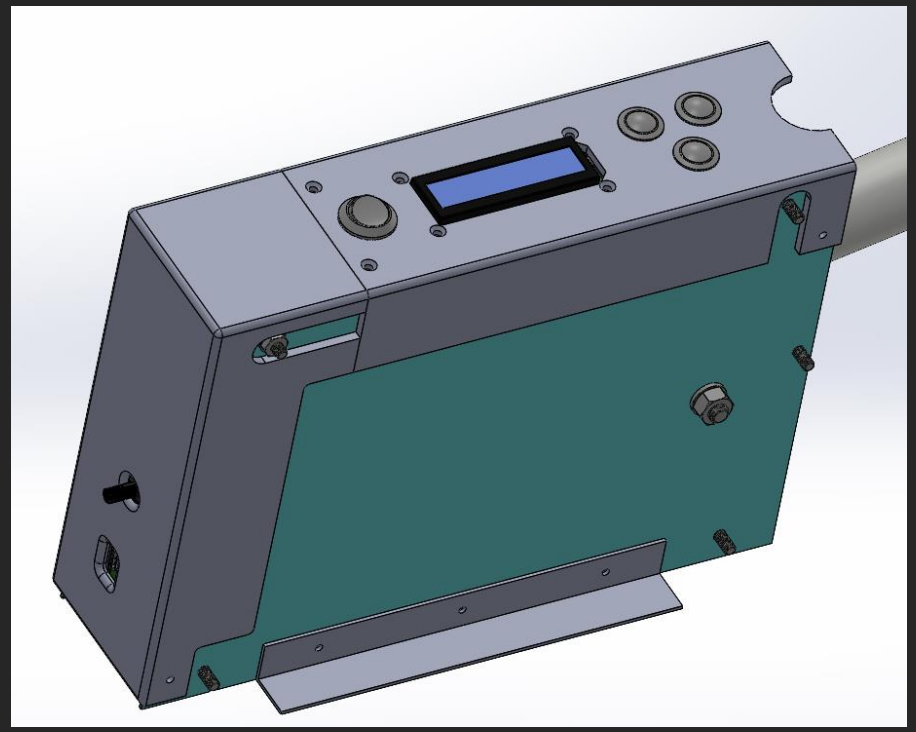
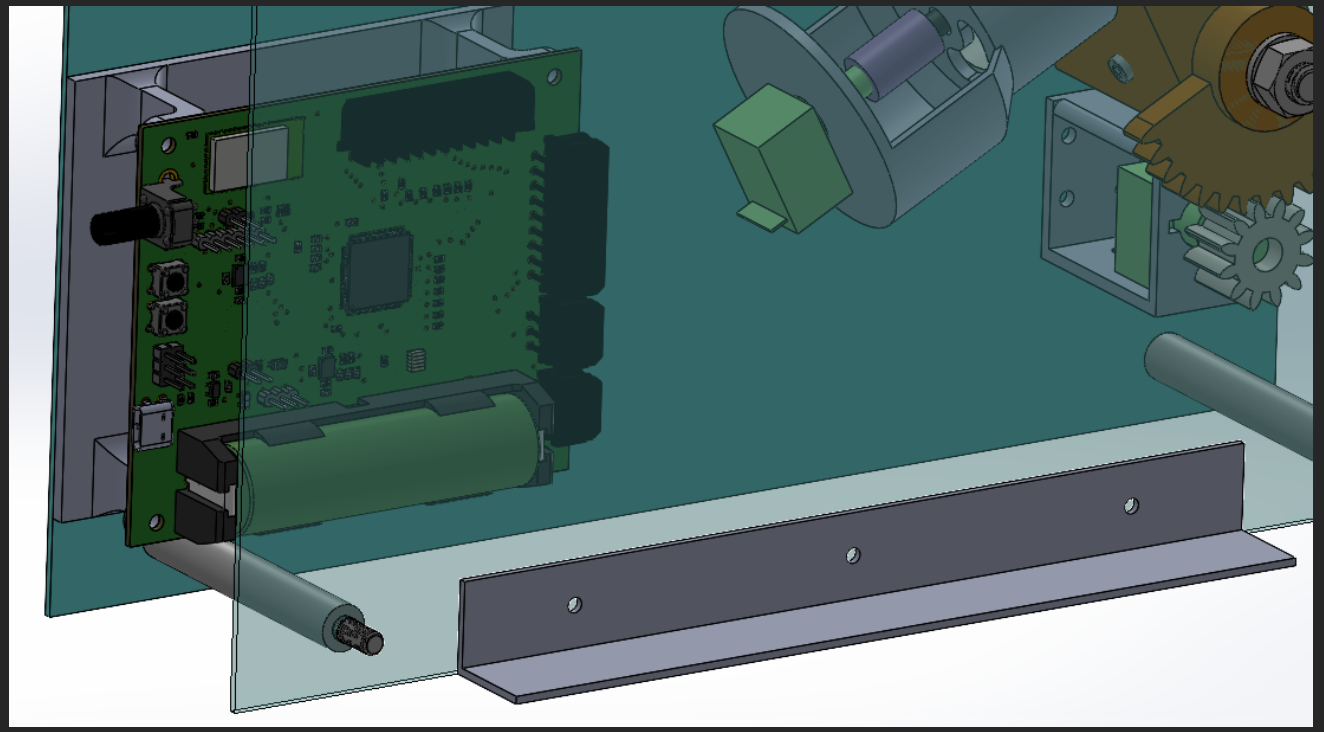
Base Unit



Base unit exterior



PCB positioning and unit mounting brackets

- Top panel controls allow for user to configure device
- PCB mounted to optimize the effective wireless connection range
- Mounting brackets designed for a variety of installation configurations

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Administrative Content

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Bill of Materials / Budget

Item Name	Part Number	Price Per Item	Quantity	Cost
18-8 Socket Screw	92196A283	$ 1.01	5	$ 5.05
Steel Hex Nut, Class 8, M8 x 1.25 mm Thread	90592A022	$ 0.53	1	$ 0.53
18-8 Stainless Steel Washer	98689A116	$ 0.07	1	$ 0.07
Stainless Steel Washer, Number 10 Screw Size	90107A011	$ 0.04	5	$ 0.20
Steel Hex Nut, 10-32 Thread Size	90480A195	$ 0.02	5	$ 0.10
10mm x 65mm M8x1.25 Shoulder Screw	92981A757	$ 3.92	1	$ 3.92
Shaft Collar, 10mm Shaft, 24 mm OD	7165N112	$ 14.20	1	$ 14.20
10 ft. Sch. 40 1 in. PVC Pipe	531194	$ 5.28	1	$ 5.28
10 ft. Sch. 40 1.5 in PVC Pipe	531111	$ 7.96	1	$ 7.96
eSun PLA PRO (PLA+) Filament 1 kg	781520911976	$ 22.99	1	$ 22.99
17 Position Male Circular Molex Connector	2021131730	$ 11.24	2	$ 22.48
17 Position Female Circular Molex Connector	2021131710	$ 21.68	1	$ 21.68
20-24AWG Tin Crimp Connector	430300001	$ 0.05	54	$ 2.81
18 Pos Male Molex Receptacle	430251800	$ 0.99	1	$ 0.99
24 Pos Male Molex Receptacle	430252400	$ 1.45	1	$ 1.45
6 Pos Male Molex Receptacle	430250600	$ 0.46	2	$ 0.92
EG2011-ND SPST Push Button	PS1024ABLK	$ 1.27	1	$ 1.27
EG2387-ND SPDT ON-OFF-ON Switch	100SP3T8B13M1QEH	$ 4.04	3	$ 12.12
EG2372-ND SPDT ON-ON Switch	100SP1T8B13M1QEH	$ 3.58	1	$ 3.58
EG2392-ND SPDT OFF-MOM Switch	100SP4T6B11M2QEH	$ 4.54	2	$ 9.08
EG1923-ND SPST Push Button	RP3502MABLK	$ 2.72	1	$ 2.72
1024 Position Absolute Magnetic Encoder	EMS22A50-B28-LS6	$ 35.51	2	$ 71.02
2.00 mm 6 Pos Female Plug Connector	5024390600	$ 0.18	2	$ 0.36
22-26AWG Tin Crimp Connector	5024380100	$ 0.06	12	$ 0.72
6x6x4.3mm Momentary Switch	Generic	$ 0.05	4	$ 0.18
2mmx8.5"x11" Adhesive-Backed Cork Sheets (2)	Generic	$ 10.77	1	$ 10.77
LCD1602 16x2 Display	ACM1602K-FL-YBW	$ 4.76	1	$ 4.76
Anti-Vandal OFF-MOM Push Button Switch	PV2S240NN	$ 4.53	3	$ 13.59
360 Brass Round Bar	BRR18	$ 5.73	1	$ 5.73
8"x11"x1/16" 3003-H14 Aluminum Sheet	S3063	$ 15.26	2	$ 30.52
3/4"x3/4"1/16" Aluminum Angle	A334116	$ 4.25	2	$ 8.50
SPST OFF-ON Rocker Switch	RR3130ABLKBLKES	$ 2.35	1	$ 2.35
Additional PCB Components	N/A	$ 14.92	1	$ 14.92
4000 mAh 18650 Li-Ion Battery	N/A	$ 3.80	1	$ 3.80
PCB Fabrication (Assembly, SMT Components)	N/A	$ 23.00	1	$ 23.00
Total Cost		**$329.62**		

This project is self-financed by the members of our team.

Sven

Division of Responsibilities

	Primary	Secondary
Logic Circuitry	David	Sven
Power System	Joseph	David
PCB Layout	Joseph	David
Mechanical Design	Sven	David
Software Design	Mark	Sven
Bluetooth Configuration	David	Mark

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Final Testing

	Description	Specification	Final/Measured
1	Cost	< $500	$329.62
2	Weight	< 20 lbs.	4.3 lbs. (max)
3	Line of Sight Wireless Connection Range	≥ 15 ft	Satisfied (Measured at 17 ft)
4	Idle Runtime (Wireless)	> 10 hours	Satisfied (Tested up to 11 hours)
5	Collective Base Size	< 1 cu. ft	2.9”x11.3”x8.25” = 0.1565 cu. ft
6	Minimum Measurable Change of Lever Angle	< 1°	0.129°
7	Angular Variance at Idle	±5% of total angular travel	±0.49% of total angular travel
8	Number of Unique Collective Heads	≥ 2 Heads	2 Heads
9	Angular Poll Rate	≥ 3 Hz	10.1 Hz
10	Collective Lever Angular Travel Range	≥ 30°	44.18°
11	Calibrated Digital Output Range	Min: 0, Max: 1023	Satisfied
12	Operating System Compatibility	Windows 10	Satisfied