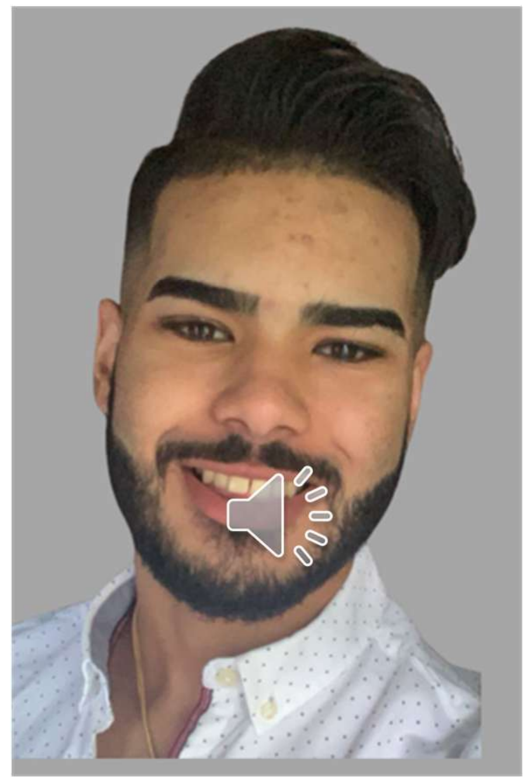
ParaPedal:
A Practical Product for Paraplegic Piano Players!

Group 15 – Senior Design

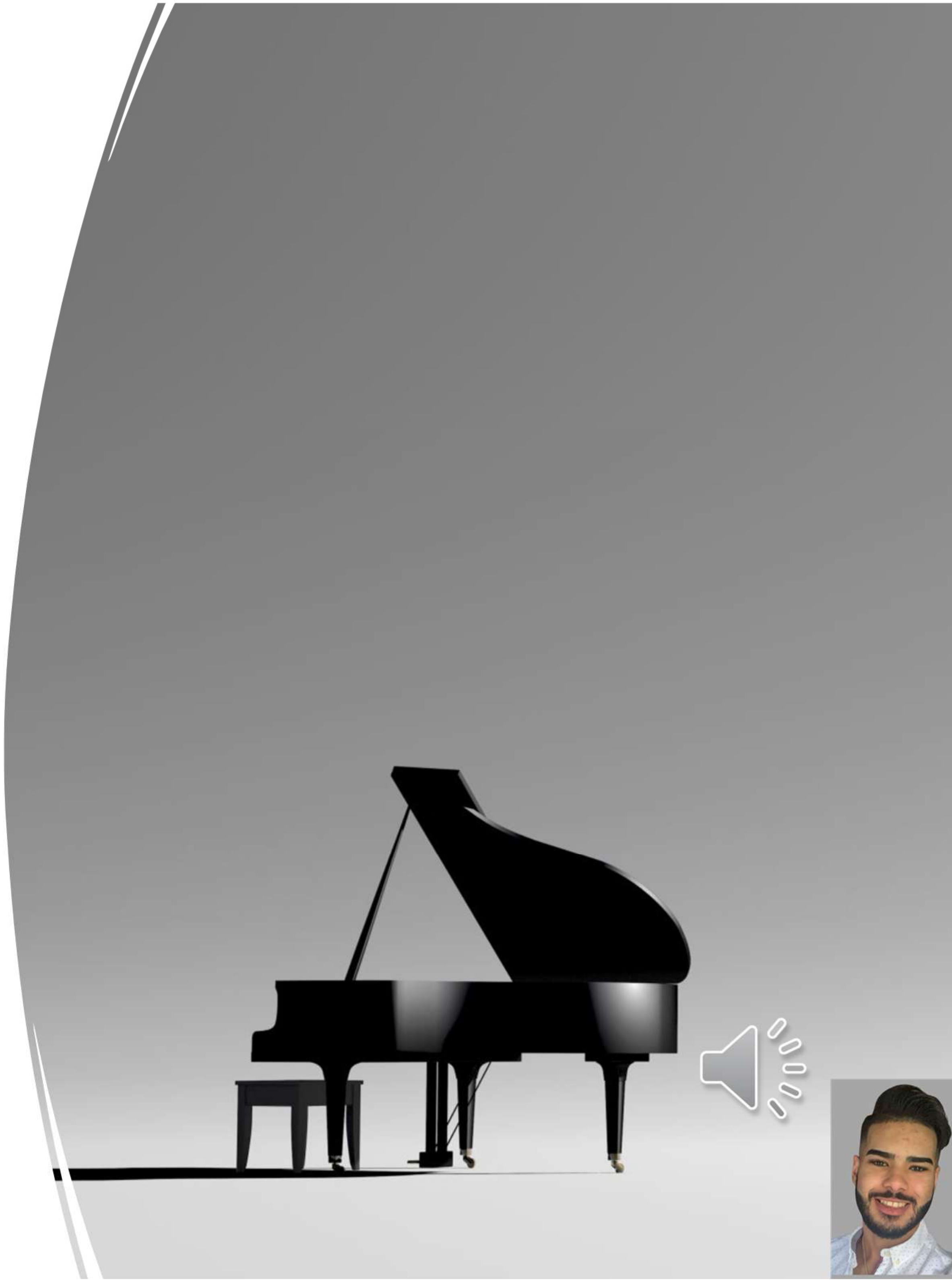
University of Central Florida



Motivation & Background

- Inspired by teammate Benedict, a pianist in a wheelchair
- Problem: Cannot use legs to press piano pedals
- Few assistive devices exist; bulky and limited



Goals

Basic: Sustain pedal, intuitive use, no piano modification

Advanced: 3 pedals, quiet motor actuation

Stretch: Breath/muscle input, phone app calibration haptic feedback

Objectives

Quantitative Objectives	
Motor System	
Motor Response Time (from user input)	500-700 Milliseconds
Maximum Power Consumption	≤ 20 Watts
User Input (Button/Dial)	
Press Detection Threshold	5-7 Newtons
Pressure Sensor Recognition Time	≤ 500 Miliseconds
Control Unit	
Voltage Input	3.3-5 Volts
Maximum Current Draw	< 500 MiliAmps
Overall System	
Device Weight	≥ 15 Kilograms
Battery Runtime	≤ 1 Hour
Communication Range	≥ 4 meters
Response Time	≤2 Second
Accuracy	75-85%
System Setup Time	≤ 2 Minutes

Engineering Specifications

House of Quality

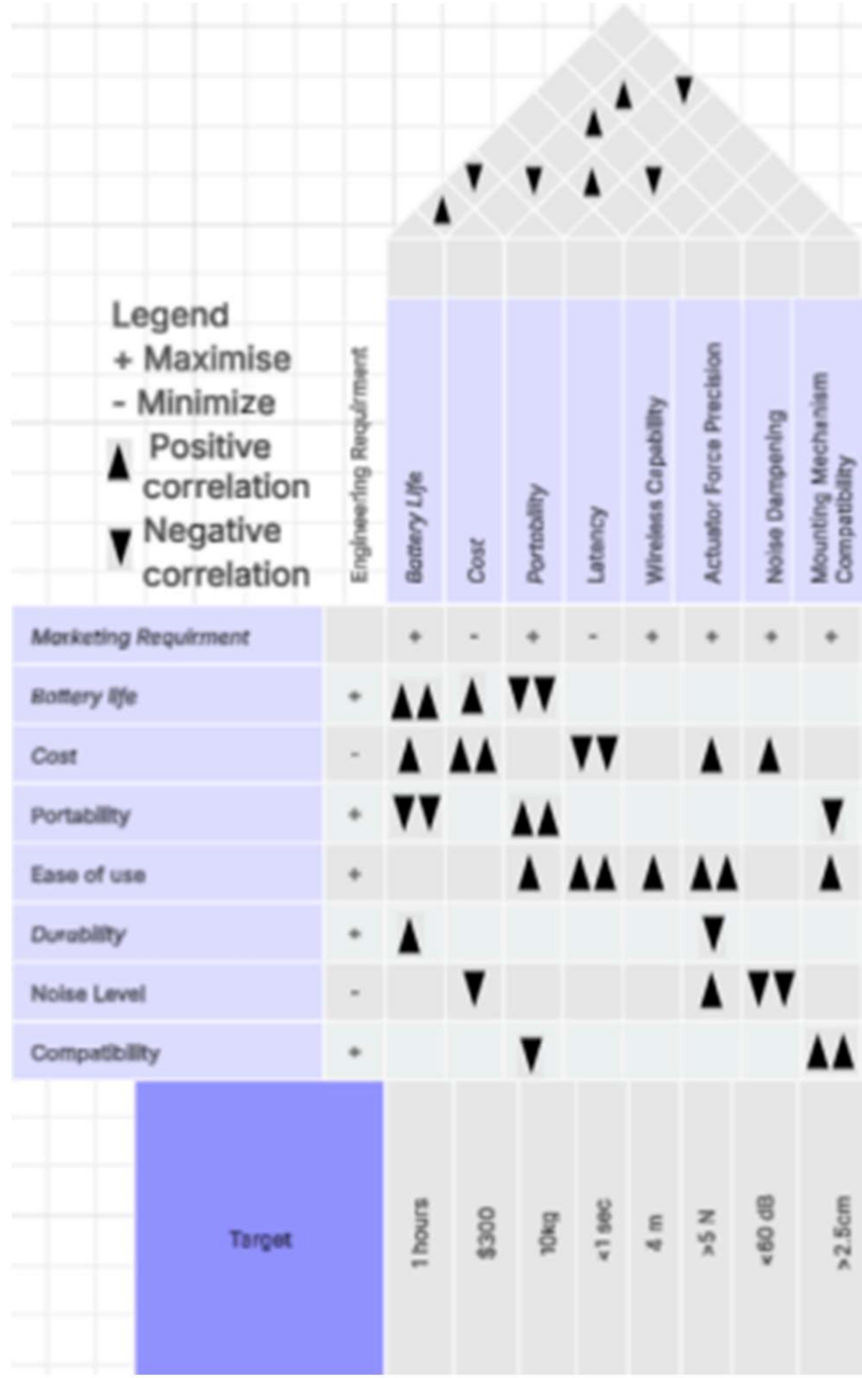
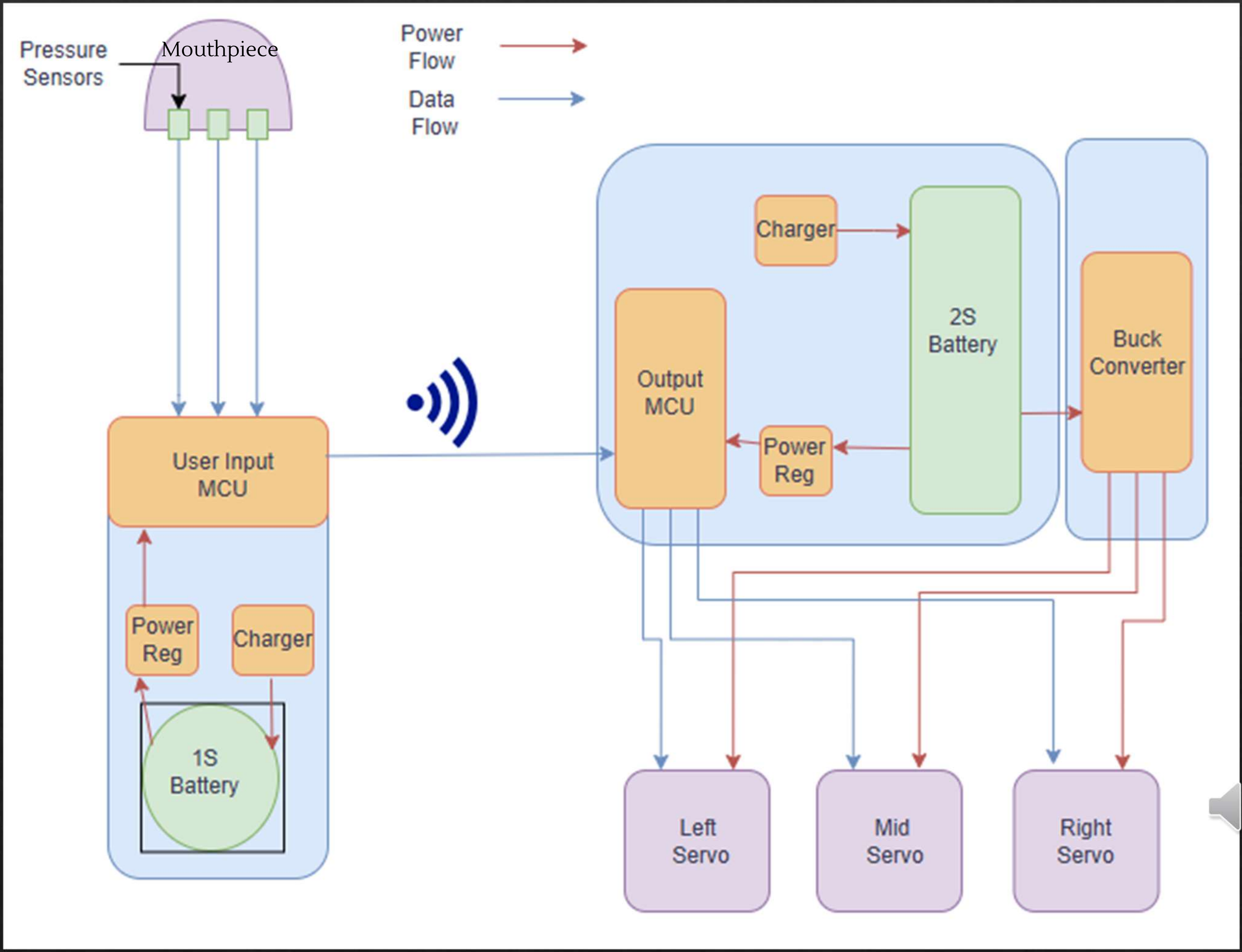


Image
of
Product

System Diagram



Hardware Selection Process

Categories: Mouthpiece, Motor, MCU, Power

↓

Compared multiple technologies for each

↓

Chose final parts based on performance, cost, usability

Mouthpiece & Sensor

Mouthpiece & Sensor

OPTION	PROS	CONS	FINAL CHOICE
BBTO Sports Guard	Cheap, easy to modify	Bulky, not discreet	❌
Goyo Night Guard	Comfortable, discreet, sleek	More expensive	✅ Final Mouthpiece
Capacitive Sensor	Non-contact sensing	Moisture sensitive, complex integration	❌
RP-S5 Force Sensor	Biocompatible, compact, simple analog signal, 1–10 N range	Limited range	✅ Final Sensor

Actuator / Motor

Actuator vs Motor

Option	Pros	Cons	Final Choice
Linear Actuator (20N type)	Direct linear motion	Bulky, slow, noisy, higher cost	❌
Linear Actuator (VEVOR 1500N)	Very high force capability	Overkill, heavy, slow, expensive	❌
Servo Motor – MG995	PWM control, decent torque	Lower torque/precision than MG996R	❌
Servo Motor – MG996R	13 kg·cm torque, ~0.17s/60°, compact & quiet	Limited rotation	✅

Microcontroller

- Final: ESP32 microcontroller
- Integrated Wi-Fi + Bluetooth
- Multiple ADC inputs and PWM outputs
- Low power,
  Arduino compatible

Microcontroller

Option	Pros	Cons	Final Choice
Nordic	Good wireless performance	Limited I/O	❌
STM32	Powerful, flexible	Complex, higher learning curve	❌
ESP32	Wi-Fi + Bluetooth, ADCs, PWM, low power	None significant	✅

Power Systems

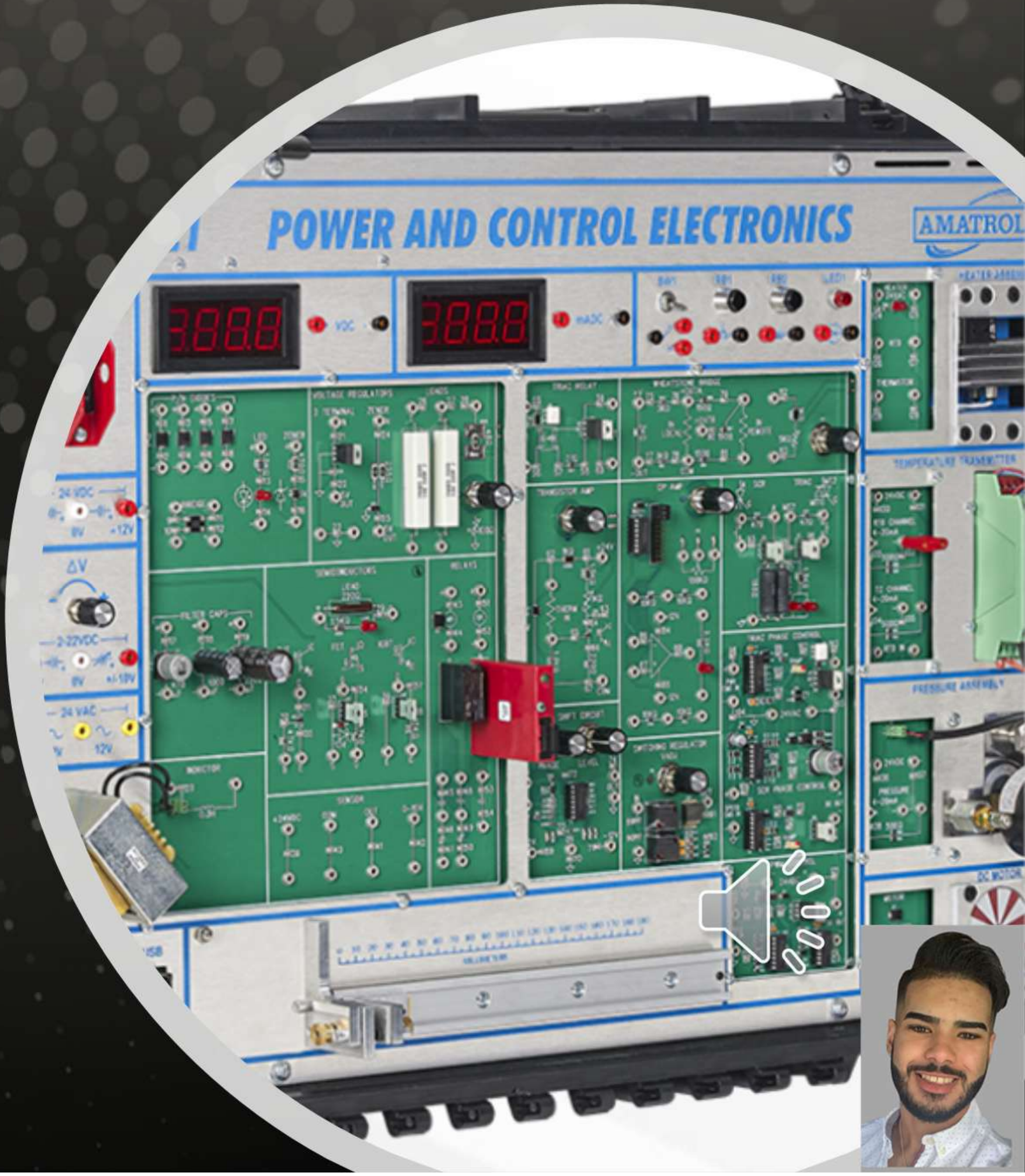
Input Board: LIR2450 coin cell battery

Motor Board: 2×18650 battery pack

Regulation: MP9928GF-Z regulator

MOSFET: SIR426DP

Charger: BQ25887



Power Supply Unit Componens

Option	Pros	Cons	Final Choice
LIR2450 Coin Cell	Small, lightweight, rechargeable	Limited capacity	✅ (Mouthpiece Input Board)
2×18650 Pack	High current supply, good capacity	Bulkier, needs balancing	✅ (Motor Board)
MOSFET – SIR426DP	Low Rds(on), efficient switching	Requires driver circuit	✅
Charger – TPB4056A20	Cheap, basic protection	Limited features, 1-cell only	❌
Charger – BQ25887	USB input, 2-cell support, safe charging	Slightly higher cost	✅

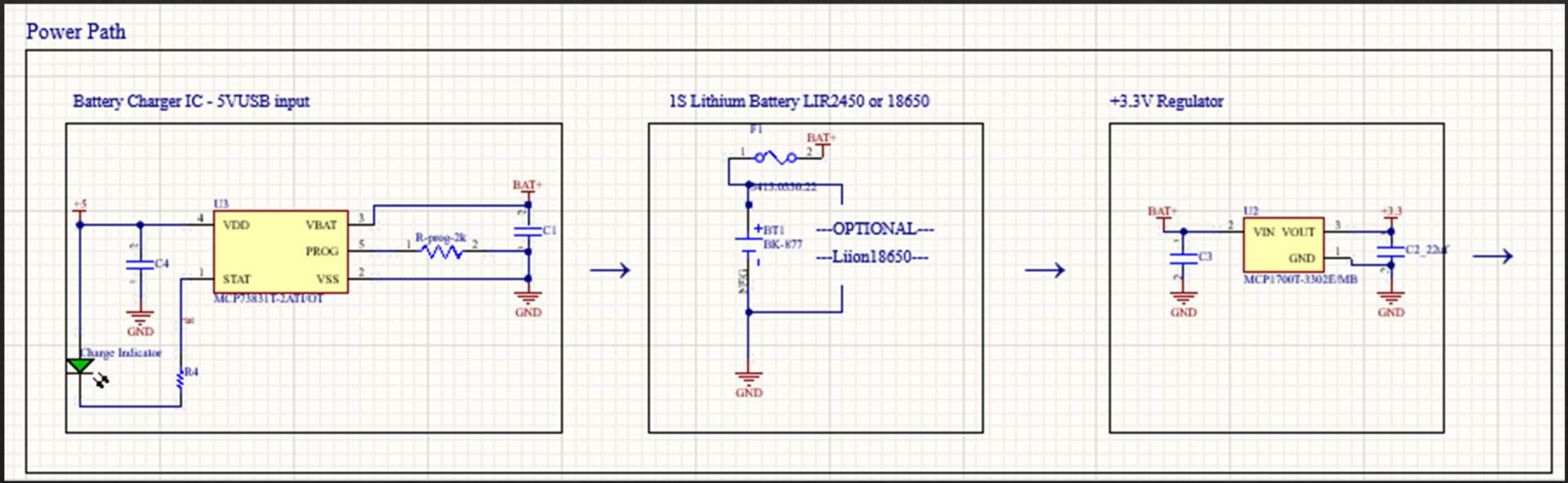
Regulators

Option	Pros	Cons	Final Choice
LDO (LP2966)	Simple, easy to use	3.3V only, low current (not for motors)	❌
XC6204B502MR-G	Flexible voltage options	Cannot supply motor currents (<1A)	❌
MP2338	>90% efficiency, up to ~3A	Near limits under motor transients	❌
MP9928GF-Z	>90% efficiency, handles motor spikes, ~3A+	Larger than an LDO	✅

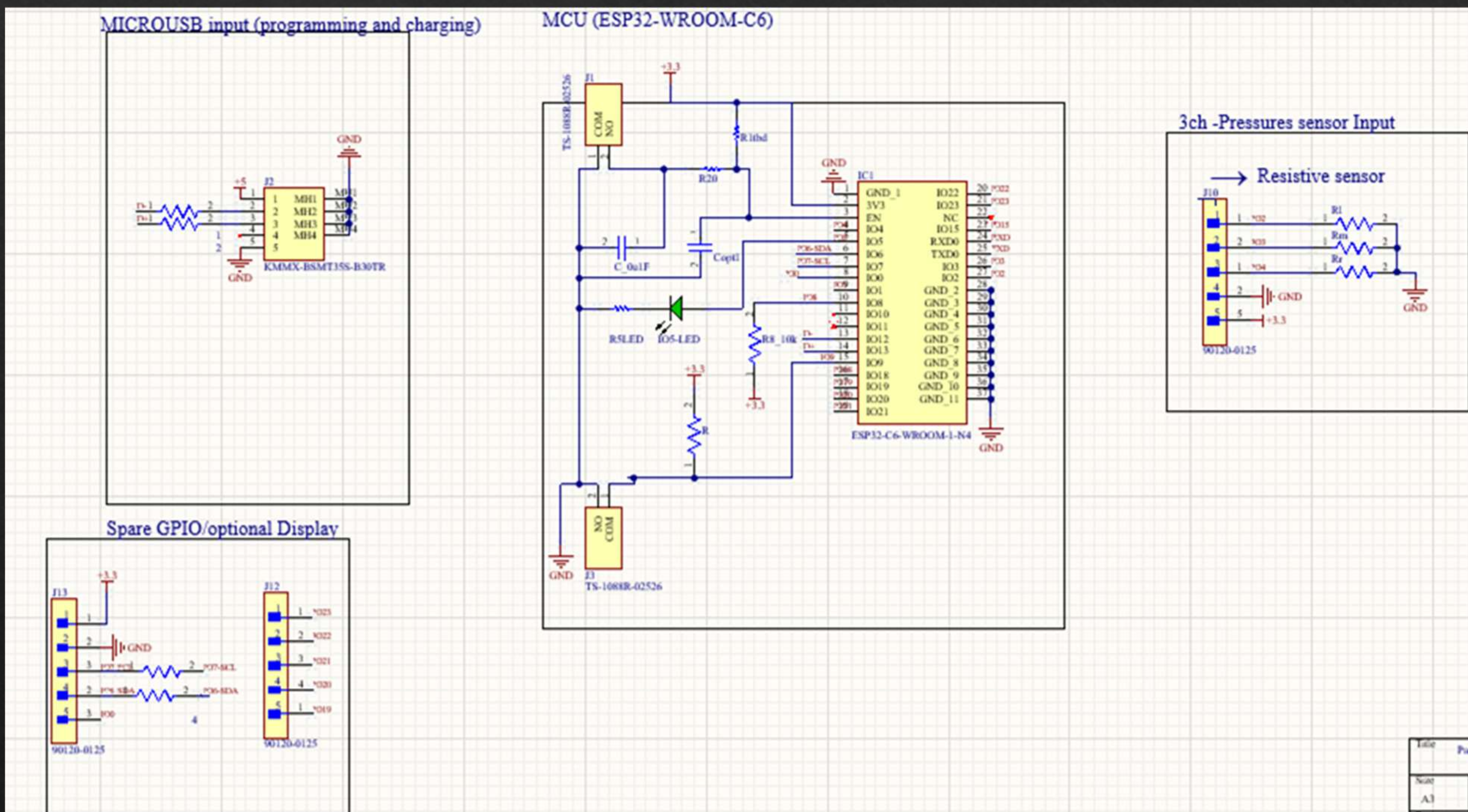
Final Hardware Summary

Subsystem	Final Choice	Why
Power	LIR2450 + 2×18650 + MP9928GF-Z + BQ25887+SIR426DP	Light, efficient, safe
Mouthpiece	Goyo Night Guard	Comfortable, sleek, hidden
Sensor	RP-S5 Force Sensor	Simple, reliable, safe
Display	SPI TFT LCD (1.8")	Clear, cheap, Arduino compatible
Actuator	MG996R Servo	High torque, fast, affordable
MCU	ESP32	Wi-Fi + Bluetooth, flexible, low power

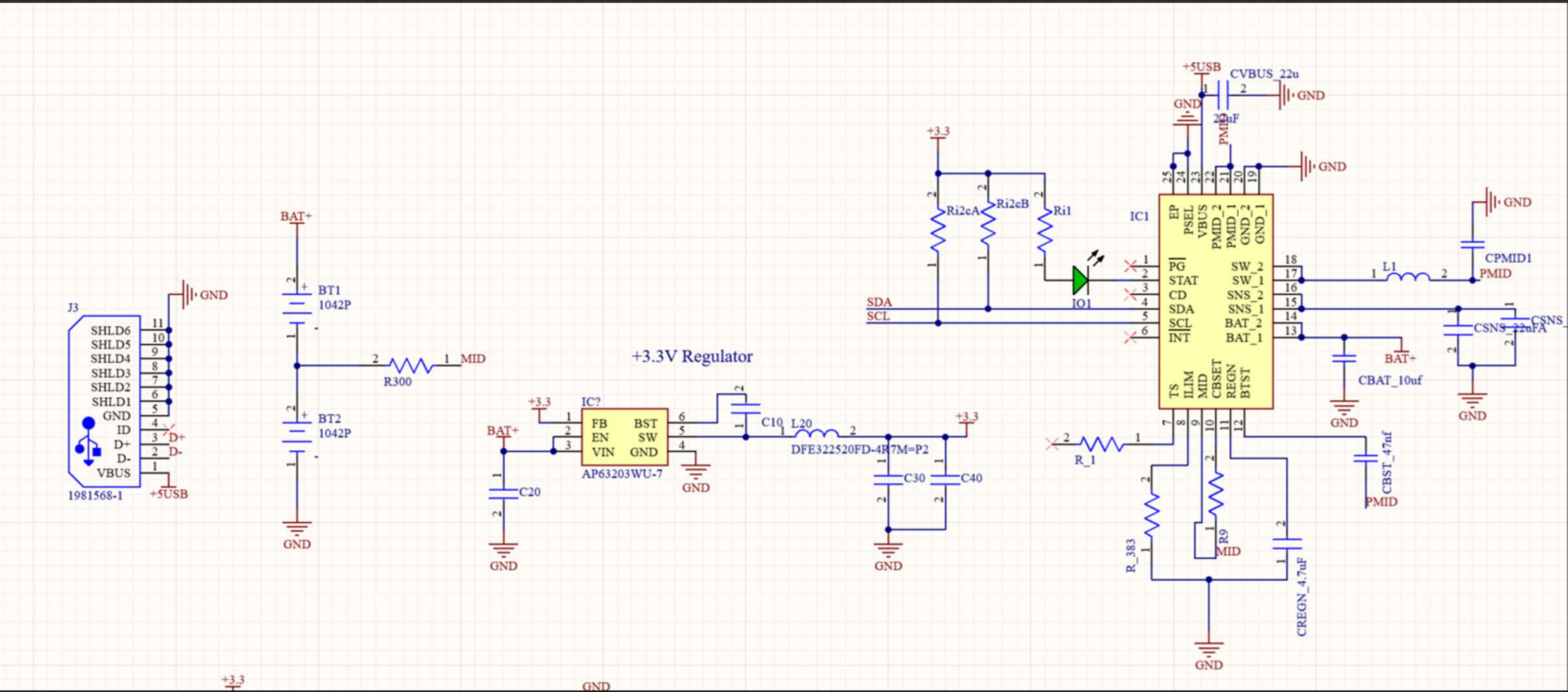
User Input Power Regulation



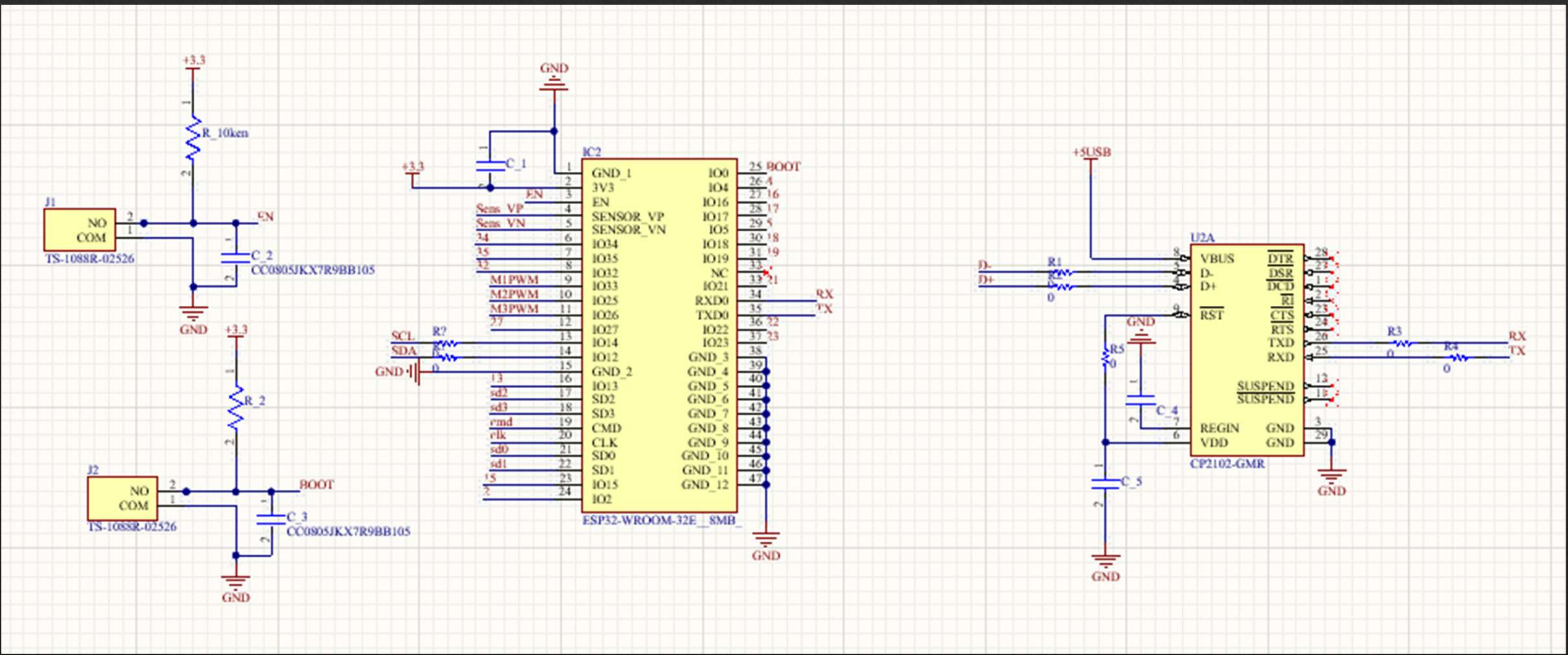
User Input Control



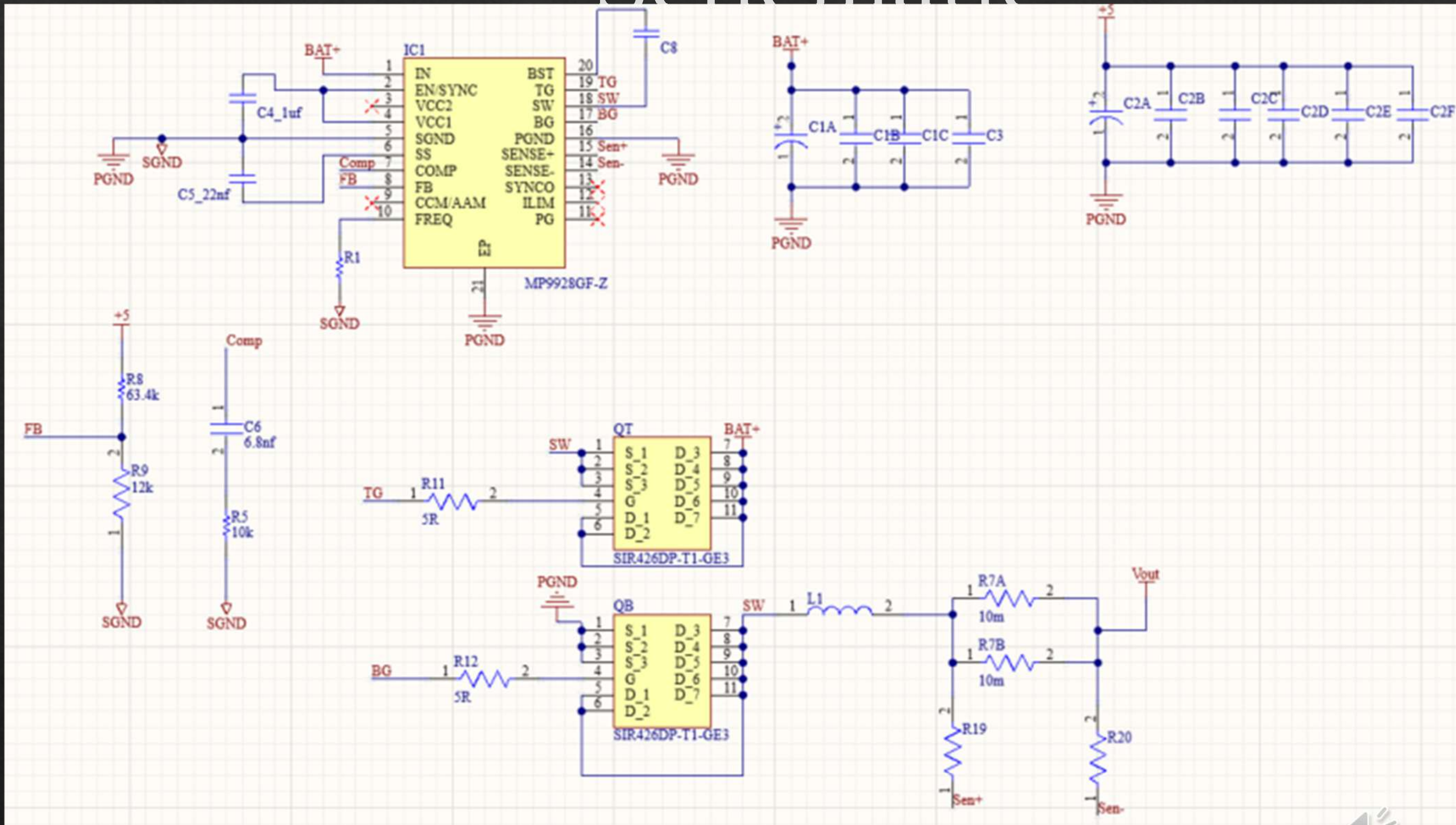
Output board Power management



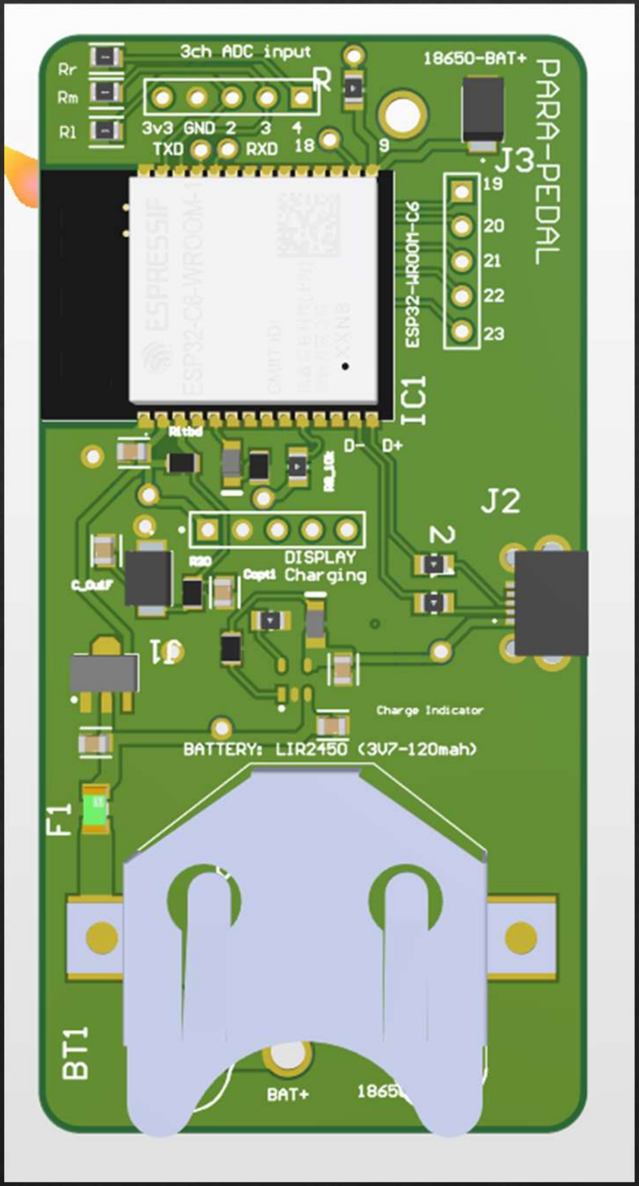
Output board Control



Buck Converter Schematic



PCB implementation



User Input Board

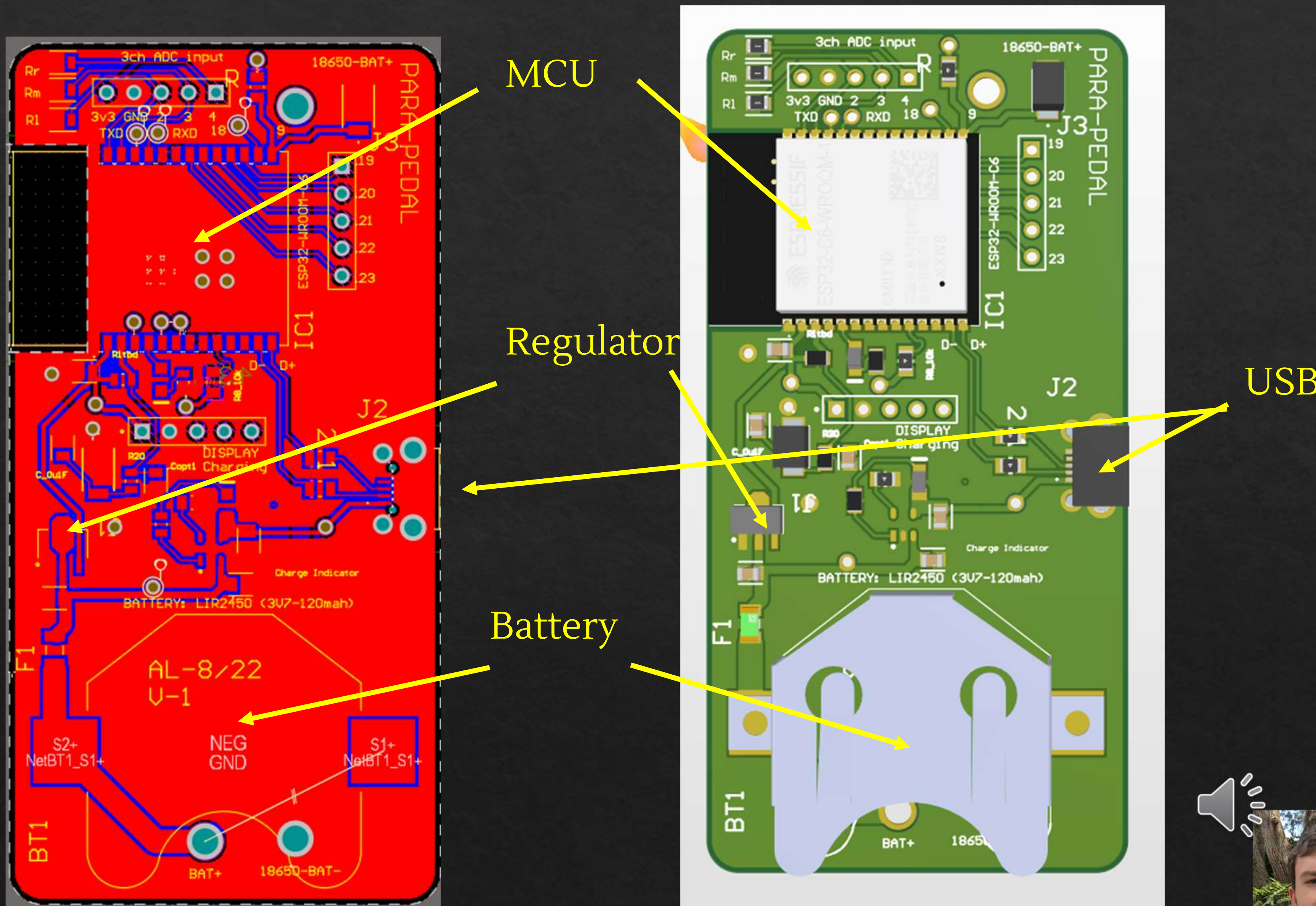
Primary Function

- To sense the user input
- Transmit this data to the output controller

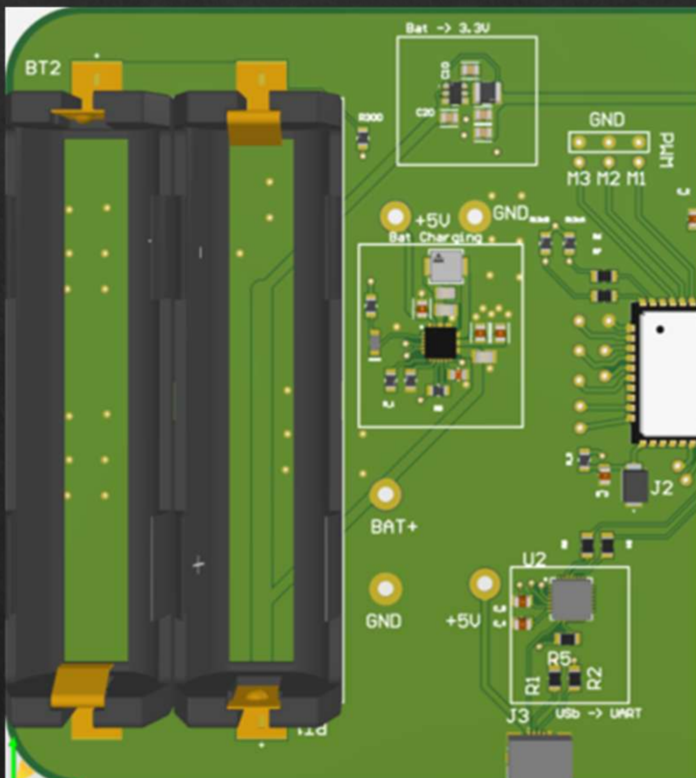
Main Components

- MCU :ESP32 - C6
- Battery :LIR2450 120mah
- Charger: MCP73831T
- Regulator: MCP1700T

User Input Layout



Output Board



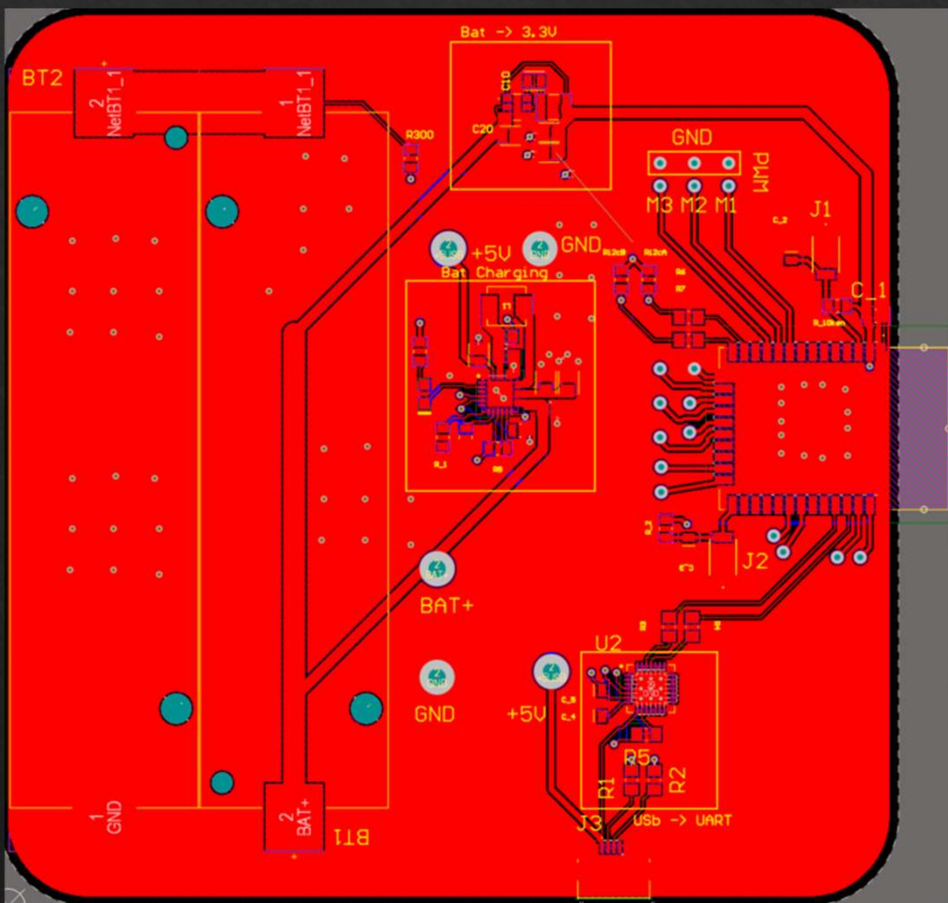
Primary function

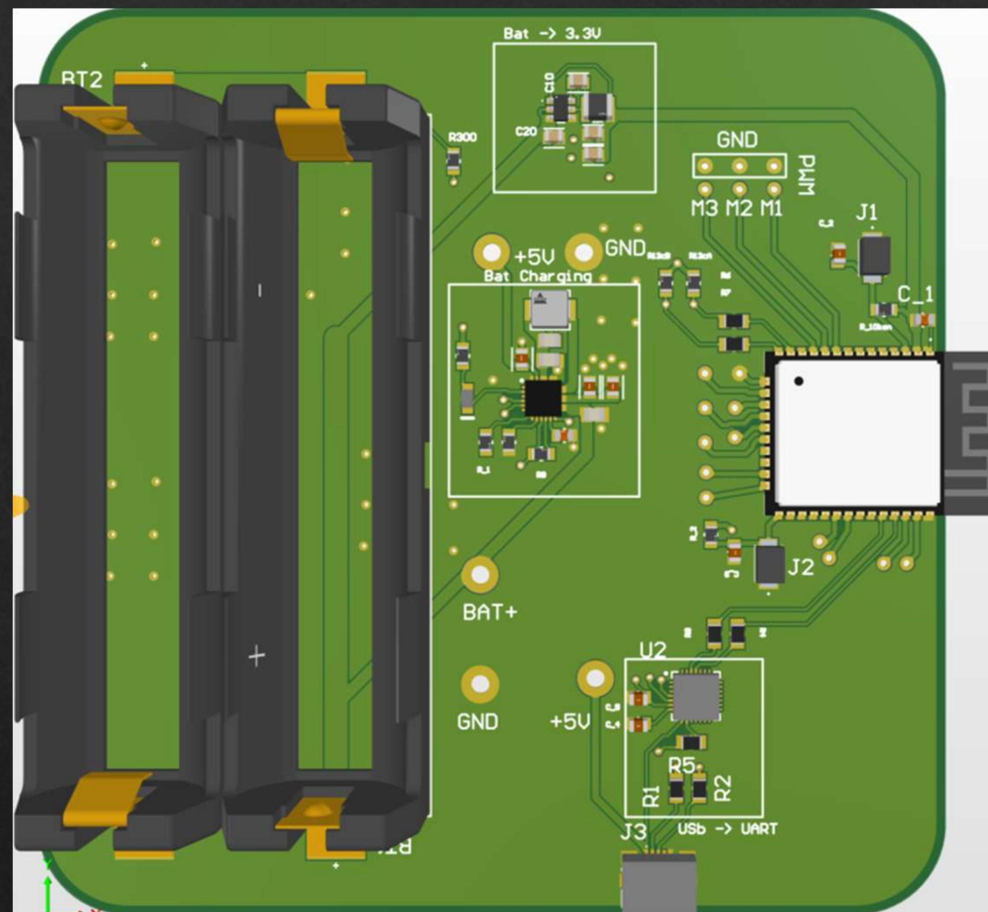
- to receive data wirelessly from input board
- Output PWM to the servo for actuation

Main Components

- MCU :ESP32 -32E
- Battery :2 X 18650 2200mah
- Charger: BQ25887RGER
- Regulator: AP63203WU-7

Output Layout





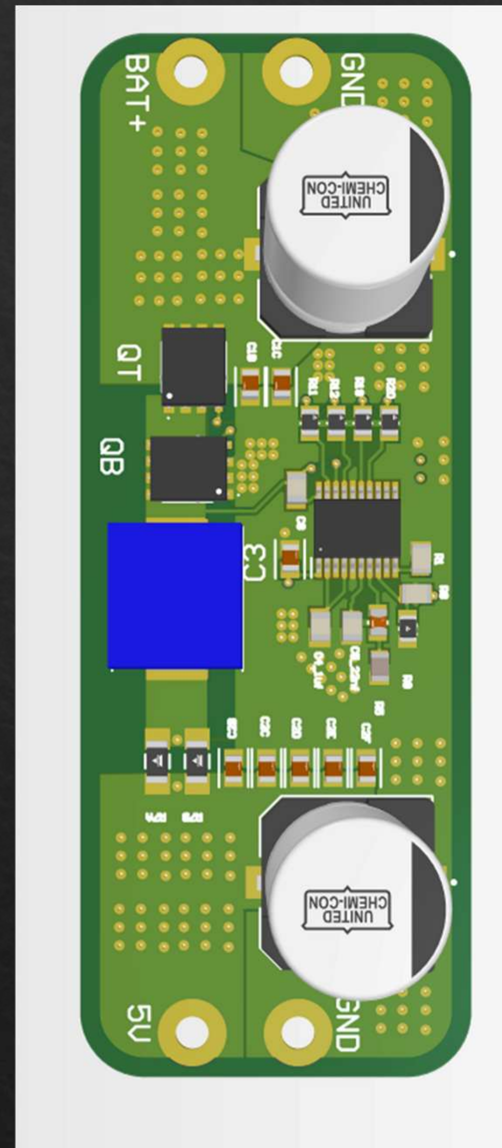
Servo Buck Converter

Primary function

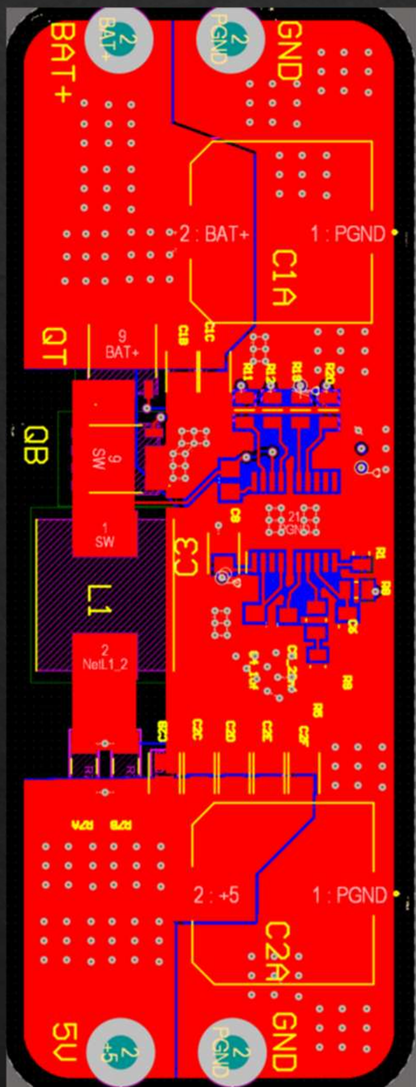
- Provide sufficient current capacity to the Motors at 5V from Battery source
- Total current = 2.5A X 3 = 7.5A

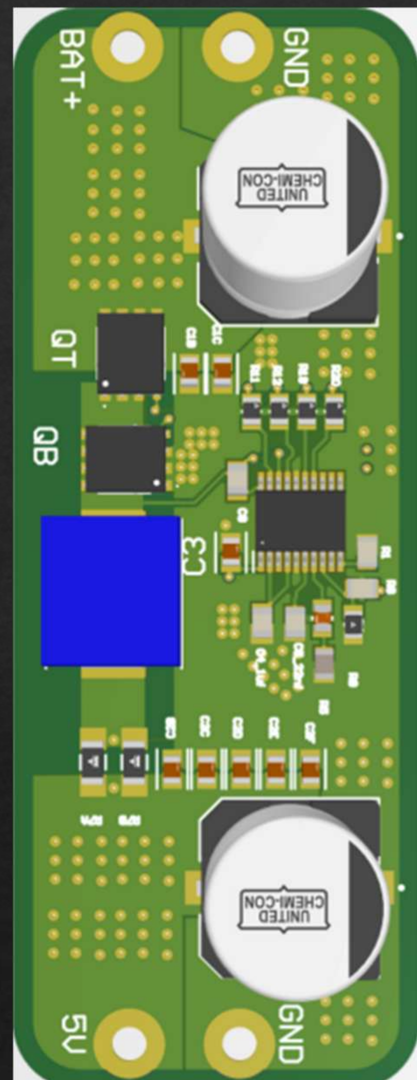
Main Components

- Buck controller : MP9928GF-Z
- Hi/Lo Mosfets: SIR426DP-T1-GE3
- Inductor : SRP1050WA-3R3M



Buck converter Layout





Wireless Protocols

Wifi	Bluetooth	ESP-now
Great complex protocol handling	Ok complex protocol handling	Poor complex protocol handling
Longer range 50-100m	Short range 10-40m	Good range 50-100
Ok Ability to handle multiple devices	Great Ability to handle multiple devices	Low Ability to handle multiple devices
Good for high throughput	Great for short bursts of information	Only small data packets
Higher power consumption	Low power consumption	Lower power consumption
High Latency	Ok Latency	Low Latency

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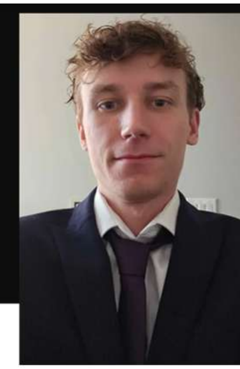
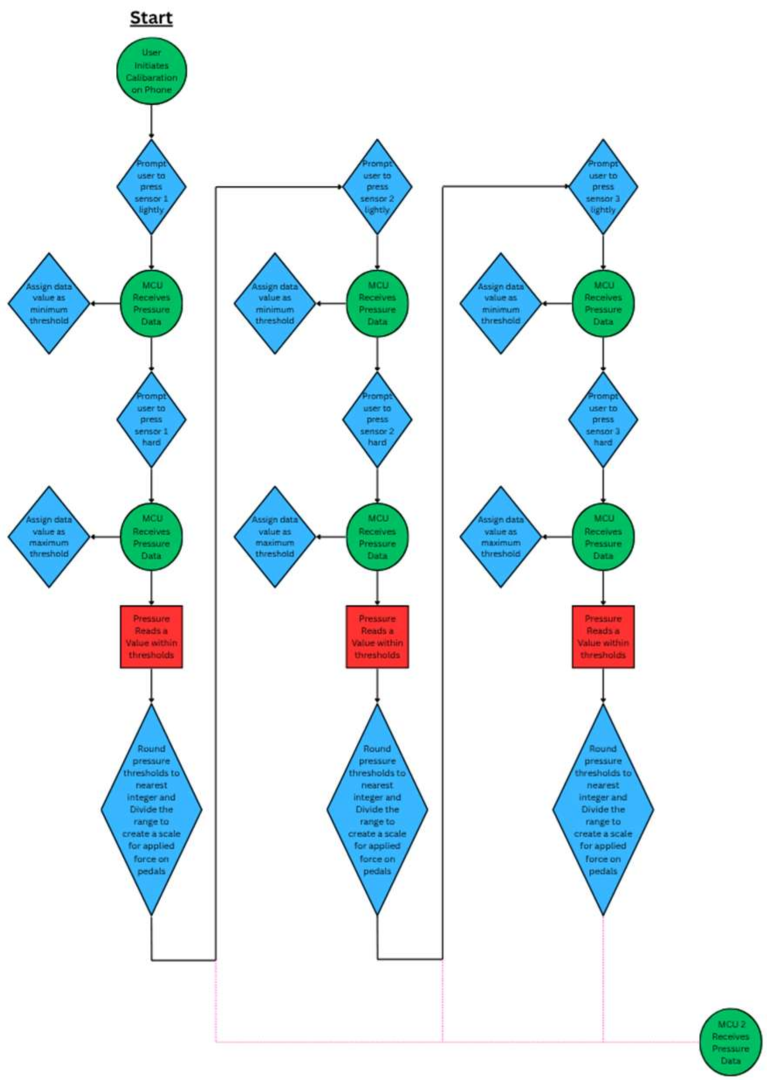
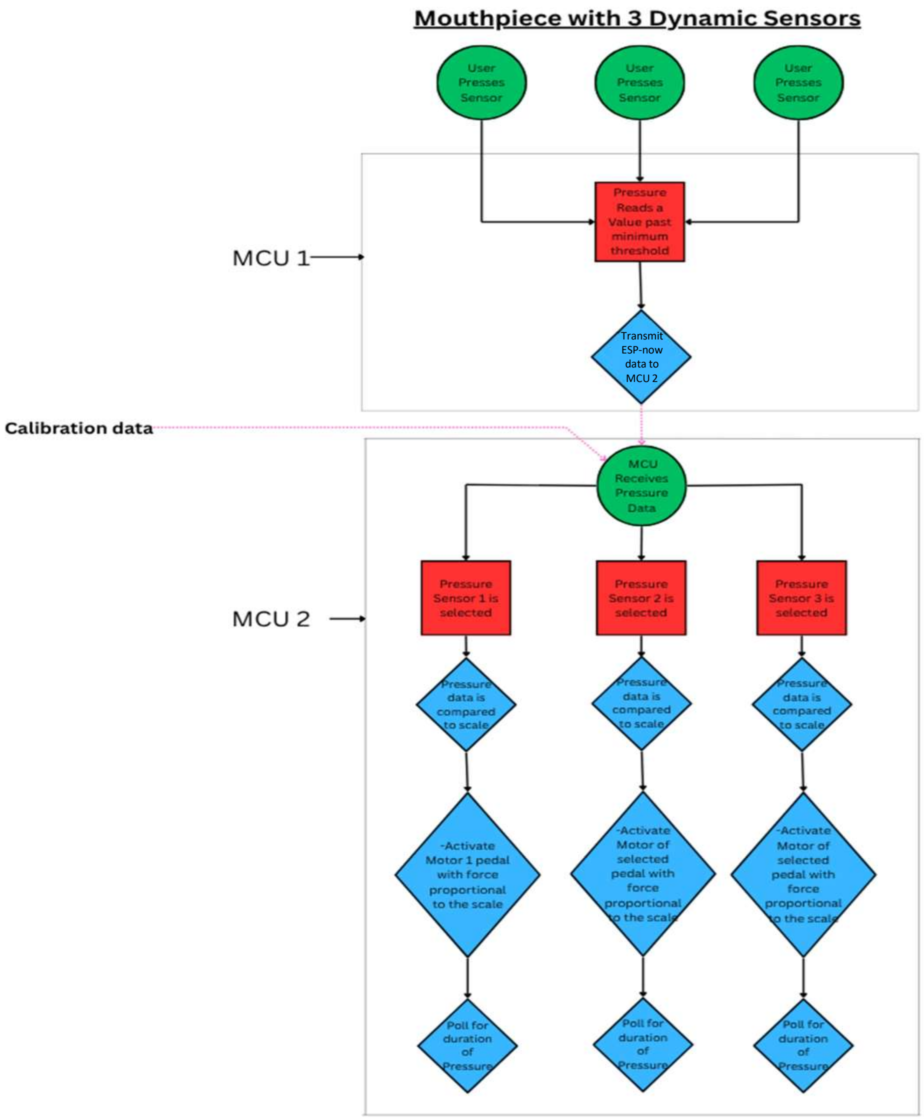
Software design



Calibration



Software design



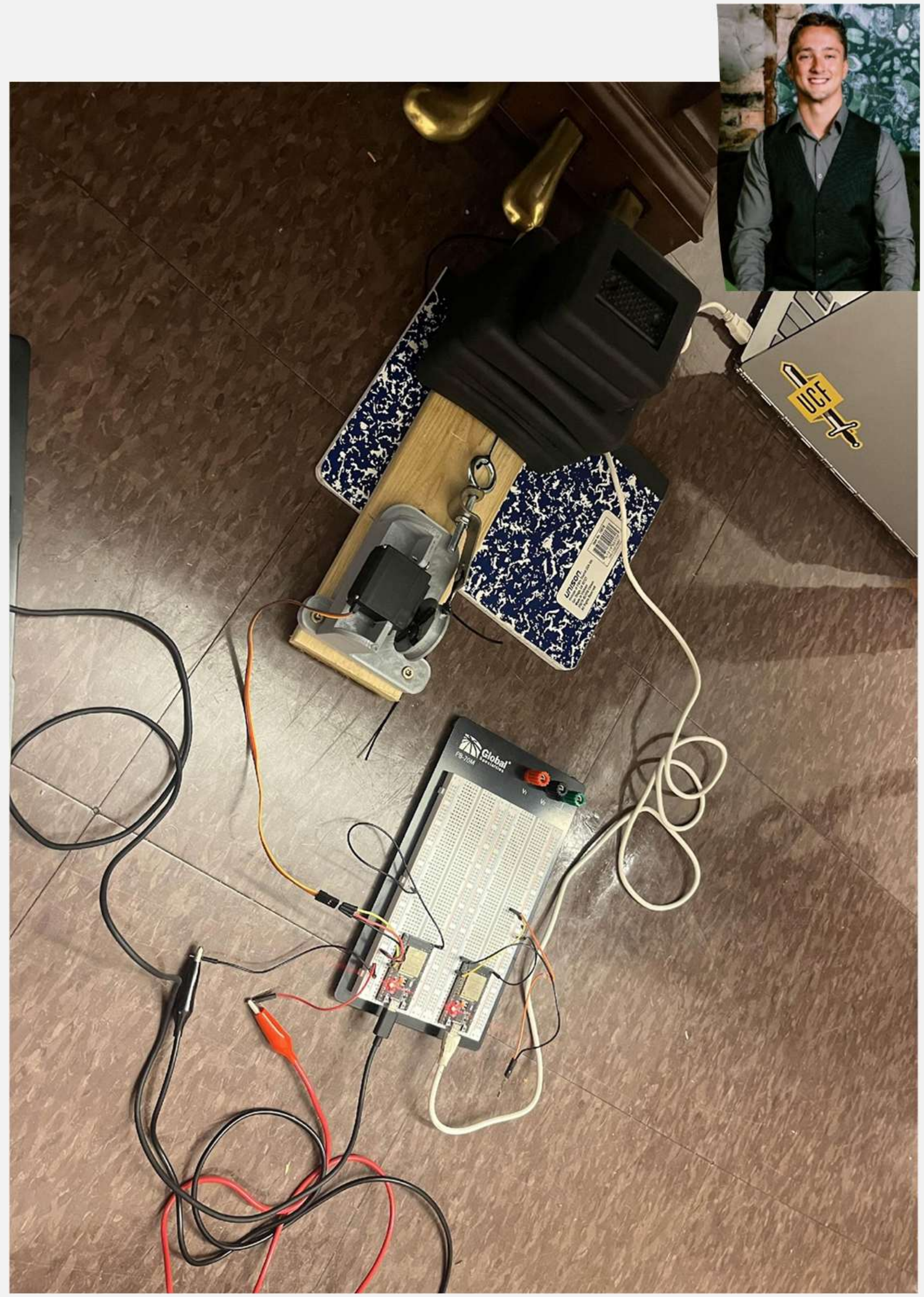
Selection of Software

FreeRTOS	Arduino
Good multitasking	Limited multitasking (single-threaded)
Deterministic RTS	Non-deterministic RTS
Good Hardware support	Good Hardware support
High RAM usage	Low overhead
Smaller community libraries	Strong Community libraries

Selection of Software

Python	C++
Vast and easy to use ecosystem	Complex Syntax
Better memory management	User-managed memory
Slower communication	Faster communication
Abstract hardware access	Direct Hardware control
Higher memory usage	Lower memory usage

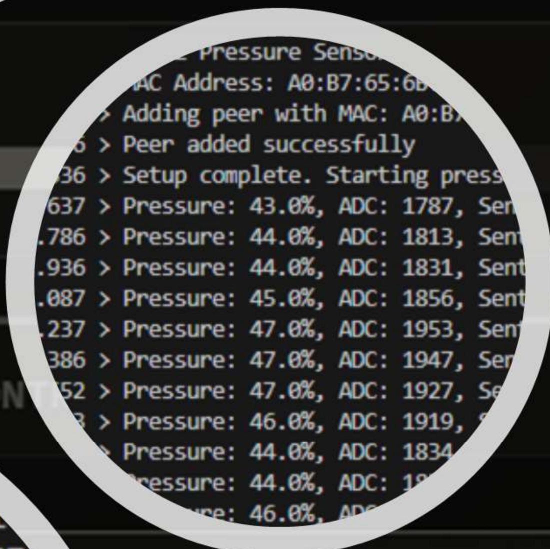
Prototype Testing

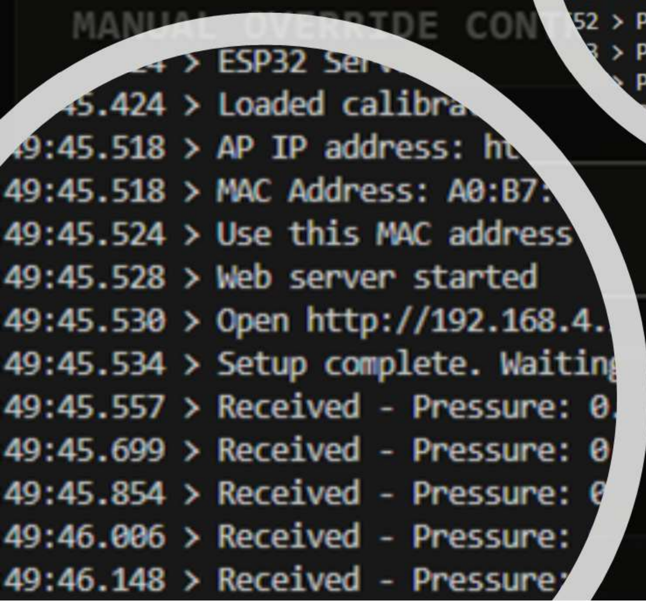


Evaluation Methodology

- **Functional Testing**: Verifying if the system fulfills specifications and requirements
- **Quantitative Benchmarks**: Measuring timing, force, latency, battery life, and wireless range.
- **User Experience Evaluation:** Feedback from our teammate Benedict who has paraplegia in terms of comfort, usability, and ease of learning.

Control Software Testing





The PWM generation system was tested by simulating sensor input values via software variables.

Motor responded immediately, transitioning smoothly between “pedal on” and “pedal off” states.

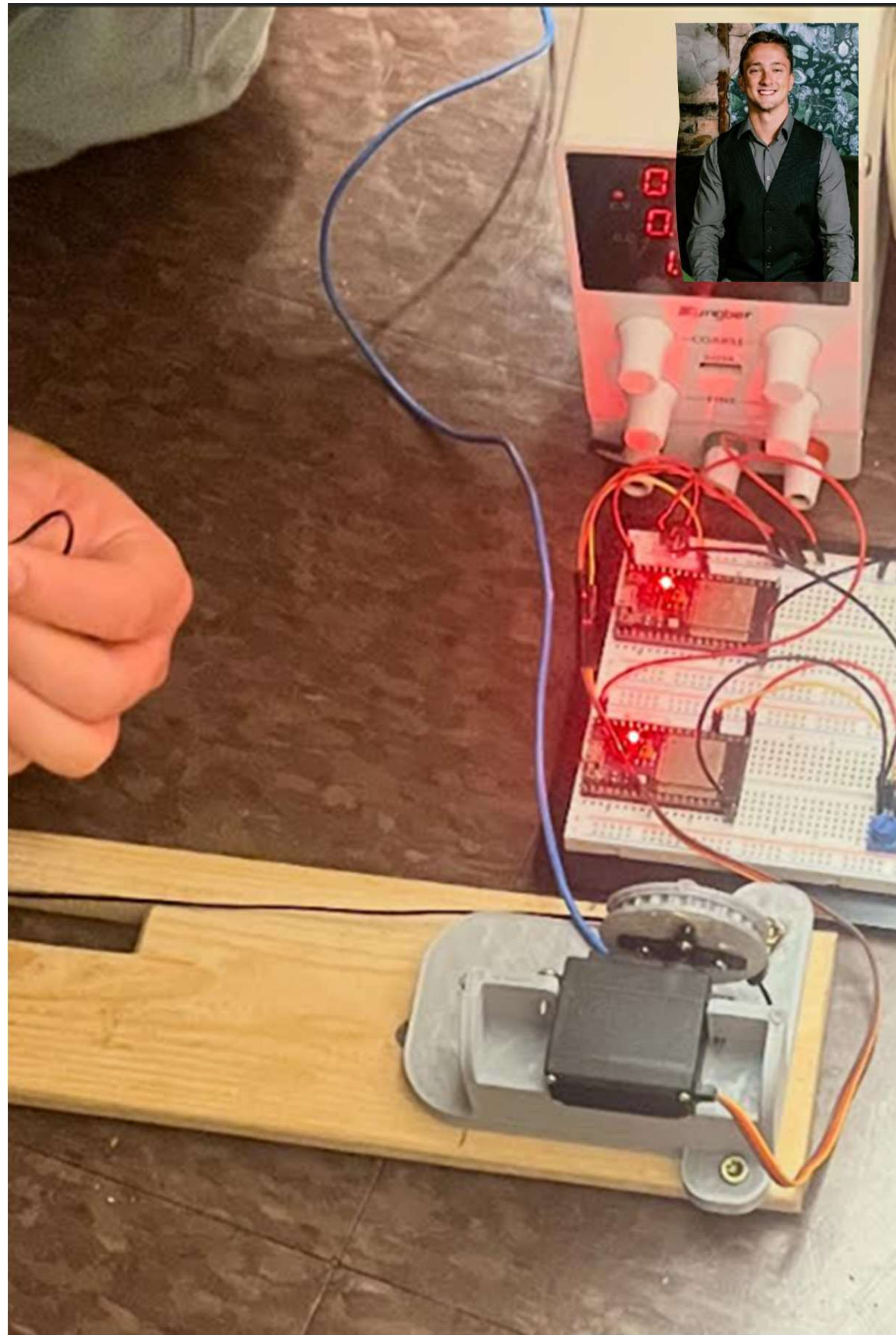
Logic loop and signal pathways from controller to servo proven functional.

Software Bugs & Solutions

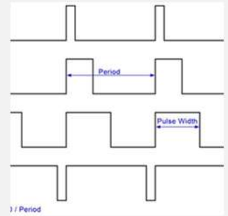
- **Problem 1:** Wasn't able to transmit the full range of the users' input.
- **Solution:** Replaced AD_6db with ADC_11db, increasing our sensor voltage from 1.1V to 3.3V.
- **Problem 2:** Servo Motor twitching, nearly unresponsive.
- **Solution:** Decreased the PWM frequency from 80Hz to 50Hz.

Motor and Structural Testing (1st trial)

- 3D-printed the servo mounting and string pulley system.
- ESP32 WROOM Development Boards connected to laptops.
- Adjustable DC Power Supply for motors.
- Potentiometer used in lieu of pressure sensors



Trial 1 Successes



Motor Control Logic: consistently produced smooth, responsive, pedal movement.

Mechanical Response: Moved the pedal with an acceptable delay

Wireless Communication: Signals were properly sent and received between boards

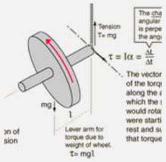
Trial 1 Challenges

- Upward Lift: When the motor pulled the pedal via the pulley, the base of the device lifted off the floor. This was due to excessive pulling force not being counteracted by sufficient downward weight or anchoring.
- Wheel Displacement: The guiding wheel occasionally rotated out of alignment. This was primarily due to unbalanced torque during actuation.
- Poor Centering: The wheel wasn’t perfectly centered with the pedal during setup. This misalignment caused uneven pulling and added sideways drag, making actuation less consistent.

Motor and Structural Testing (2nd trial)

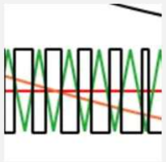
- Added a stronger, upgraded wheel for better torque
- Screws added to secure connection between the wheel and motor shaft
- Custom guiding wheel added for the pulley system stability.
- Weights added to base to mitigate the lifting effect.

Trial 1 Successes



Motor Torque within spec

Secure connection between the wheel and motor shaft



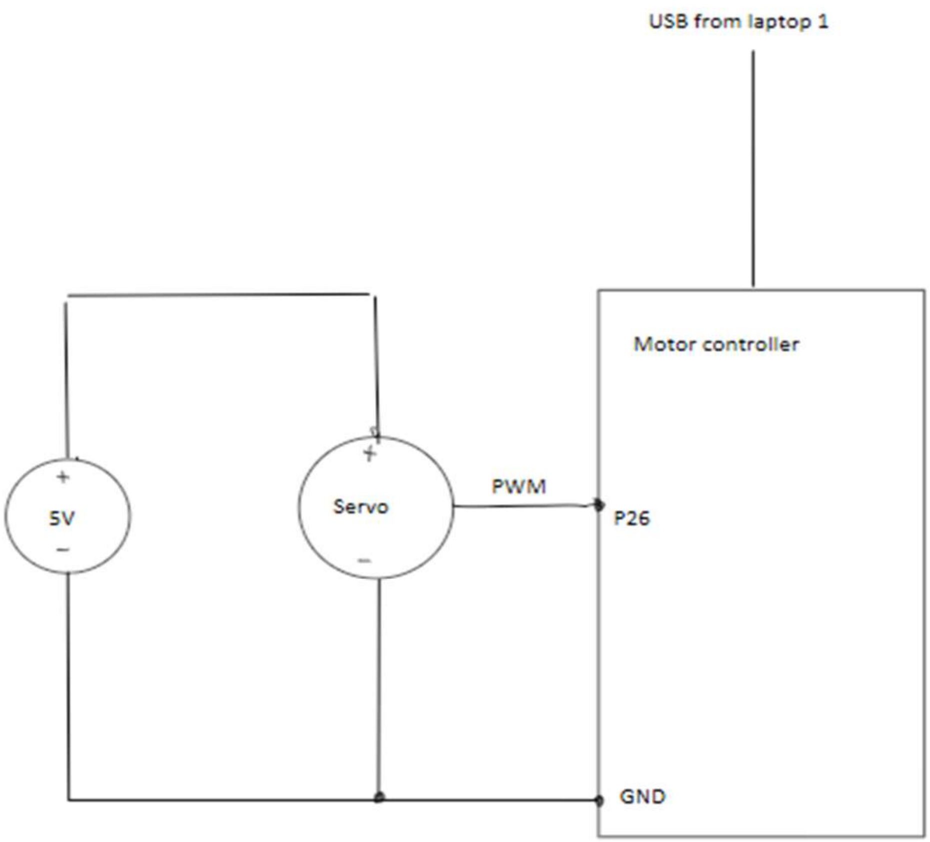
Improved pulley system stability

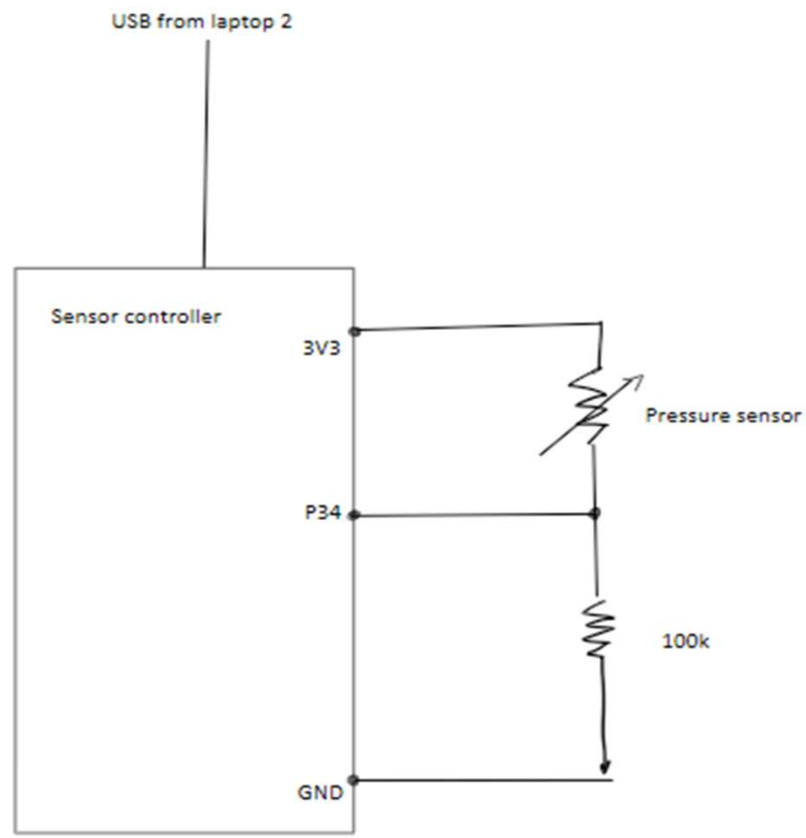
Lifting effect mitigated

[Visual: ESP32 board image]

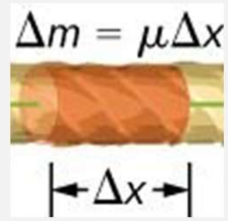
Motor and Structural Testing (2nd trial)

- Bolt/nut adjustment system for fine control of string tension
- Pulley system was redesigned with greater clearances to reduce friction.
- Resistive pressure sensors used in mouthpiece implemented.

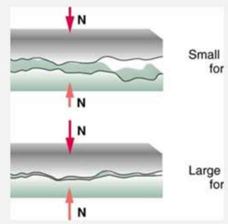




Trial 3 Successes



Fine control of spring tension.



Reduced friction in pulley system.

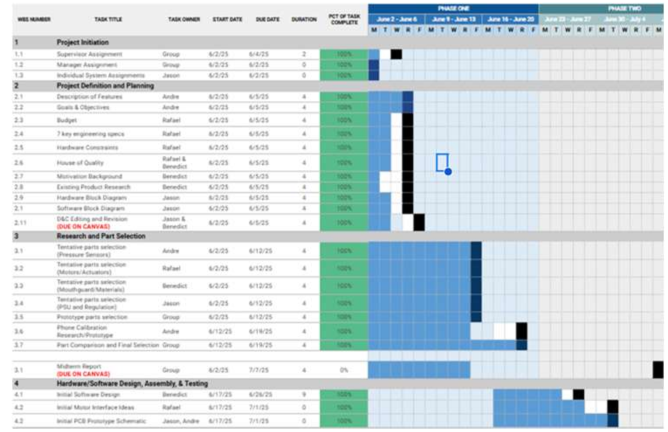
Pressure sensor functionality confirmed.

Comment	Description	Designator	Footprint	LibRef	Quantity	Manufacturer Part Number	Cost
MP2338GTL	Battery to 5V Buck				10		$11.30
MS621FE-FL11E	MS Lihium Rechargeable Battery	Lion Battery?	SEIK-MS621FE-FL11E-2_V	CMP-00029-00000-1	2		$13.29
ESP32-WROOM-32D	WIFI MODULE 32MBITS SPI FLASH	PeripheralController	FP-ESP32-WROOM-32D-MFG	CMP-194065-000003	1	ESP32-WROOM-32D	$5.38
Boot Select button	Push Button Normally Opened	S1		Push Button NO	1		$1.94
CP2102-GMR	Single-Chip USB to URAT Bridge	U?	SLAB-QFN-28-3125x3125TP_M	CMP-2000-04924-1	1		$8.88
LP2966IMM-1833/NOPB	Dual 150mA Ultra Low-Dropout Regulator	U?	MUA08A_N	CMP-0062-02215-2	10		$15.40
BQ25887	Battery Manager				2		$10.00
18650 Battery Case					2		$9.99
18650 Batteries					2		$3.00
Satin String Spool					1		$6.99
Servo Pulley					20		$3.99
MG996R	Servo Motor				4		$18.00
RP-S5	Resistive Pressure Sensors				2		$9.50
Mouthguard					20		$8.99
						Total Budget	$122.66

Work Distributions

- While there is a table of work distributions. all members are actively communicating and working on every aspect of development.
- This allows all members to learn about topics we are weak in and teach others about topics within our strong areas.
- The Gantt chart is a more accurate depiction of our work distributions.

Gantt Chart



Work Distributions

Name	Primary Tasks	Secondary Tasks
Jason	Manager, Power	PCB
Andre	PCB Design	Coding
Rafael	Motors	PCB
Benedict	Coding	PCB

Progress and Plan for Completion

We have ordered our PCBs to evaluate the system's abilities to meet requirements, before implementing our stretch goals.