Prosthetic Control Board

Team 46

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11.3
MILLION

people with hand amputations worldwide.

80%

live in developing nations.

< 3%

have access to adequate, affordable, prosthetic devices.

data courtesy of Psyonic

Abstract

The Aim:

- Provide inexpensive and feature-filled prosthetic devices
- Have all costs covered by insurance

The Next Steps:

- Migrate to a new microcontroller architecture (ARM)
- Release product under FDA Class I specification
- Prepare for mass-production

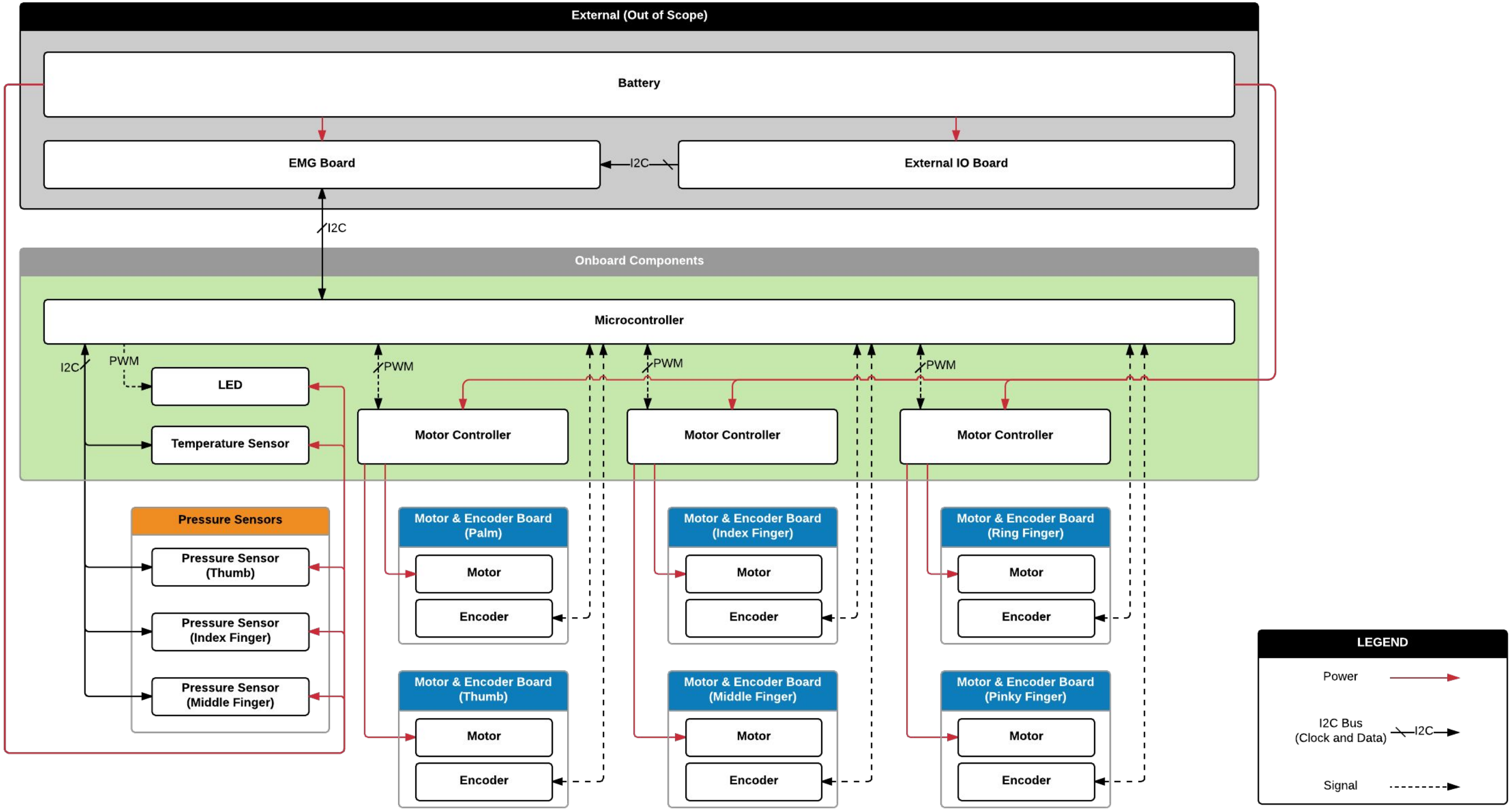
PSYONIC

"Redefining human."

Objectives

- PCB that fits in PSYONIC's current hand
    - Interface with motors, sensors, and other subsystems
- New microcontroller architecture (ARM)
- Multiple I^2C connections for pressure sensors
- On-board temperature sensor
- Status LED
- Conformal coating

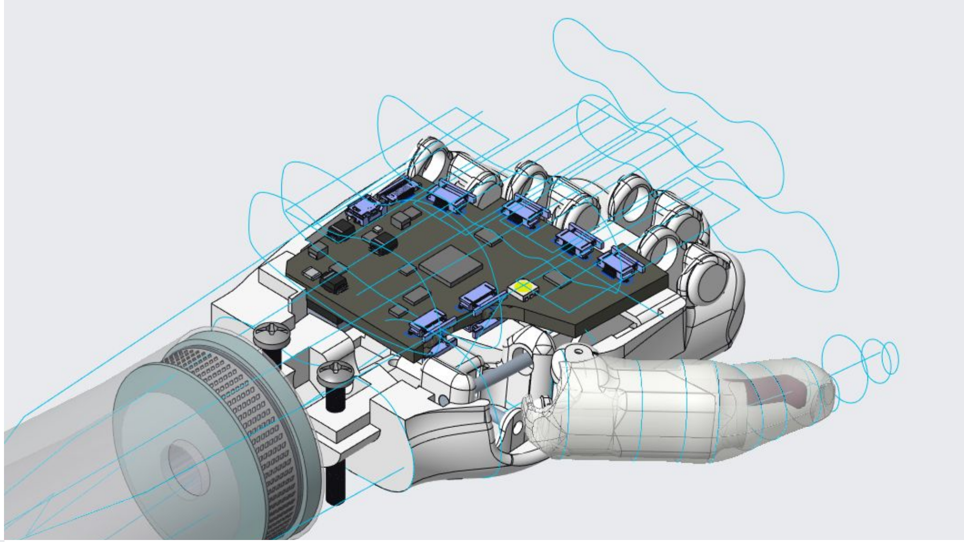
Modules & Sub-Components

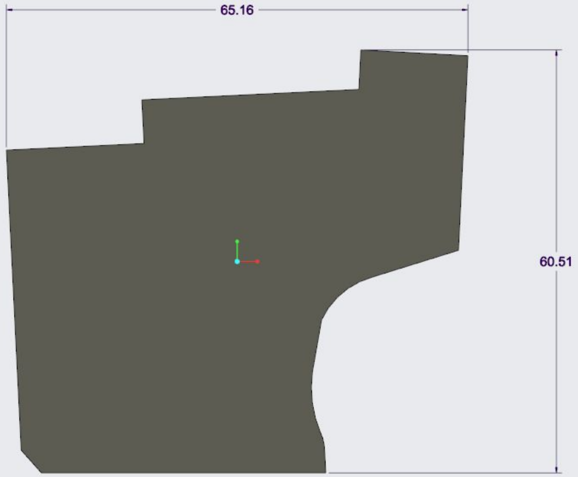


CAD MODEL

Artist's Rendition →

Tight physical constraints determined the shape and size of our circuit board.





DIMENSIONS

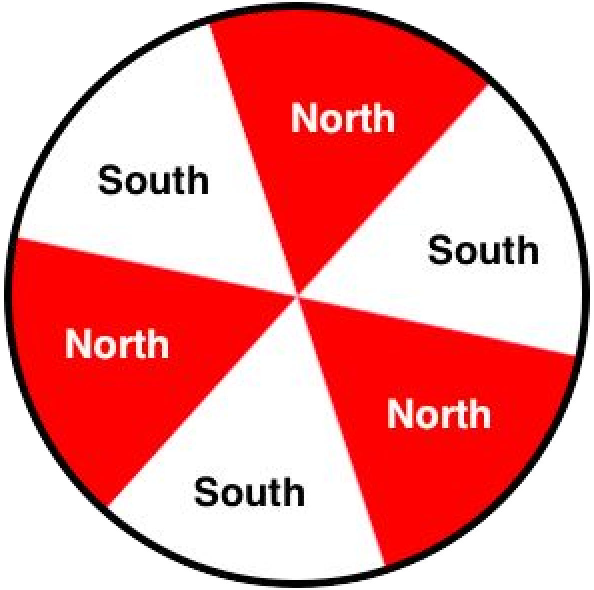
& Constraints

These constraints are vital to a manufacturable system.

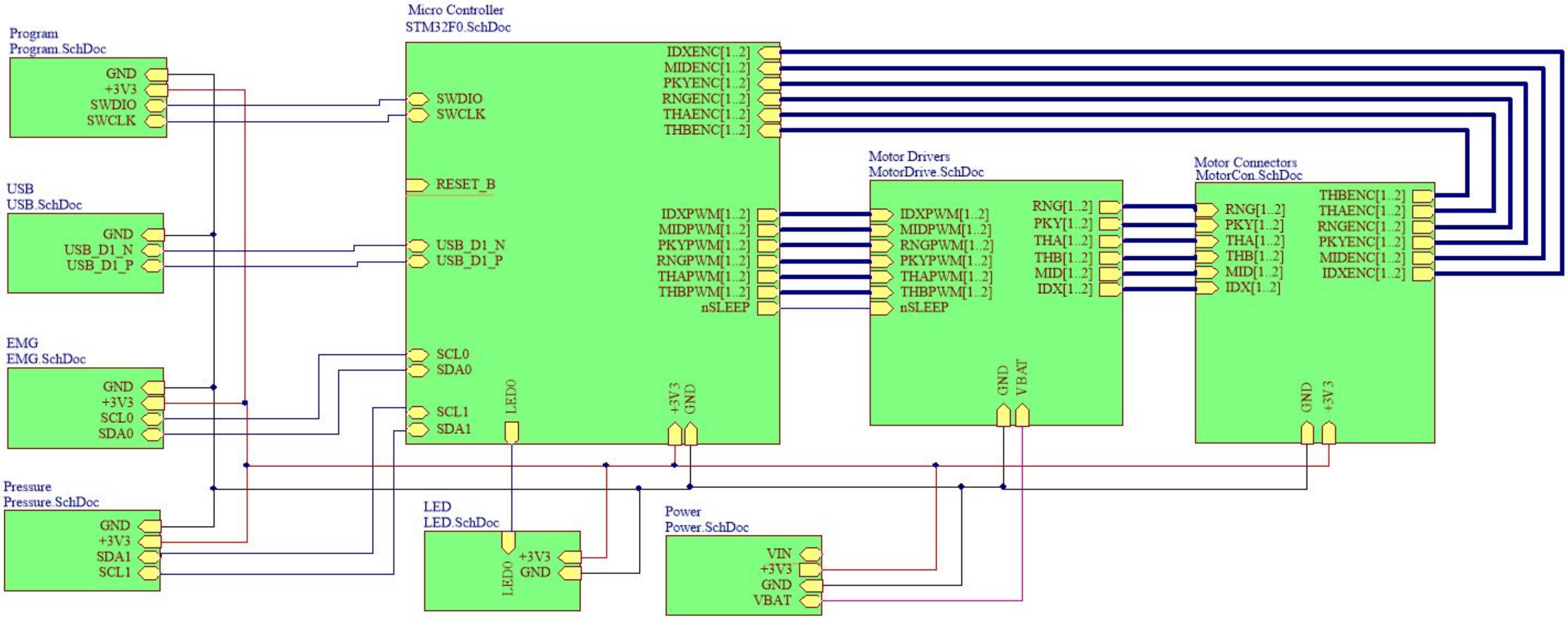
Board size drove component package selection.

Encoder Calculations

- 2 hall effect sensors
- 6 magnetic regions on the rotor
- Motor RPM: ~32000
- 10% tolerance for speed
- Max frequency: ~7000 Hz

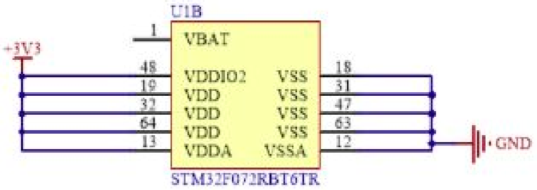


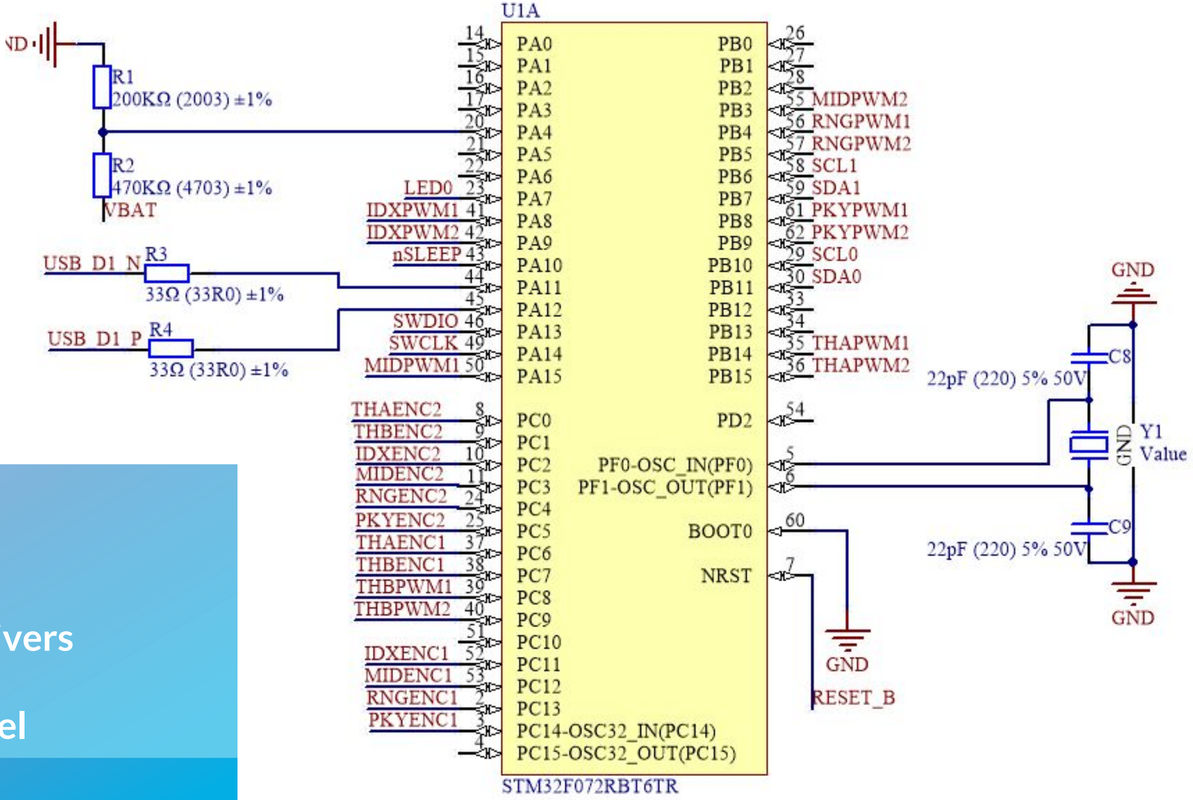
Schematics



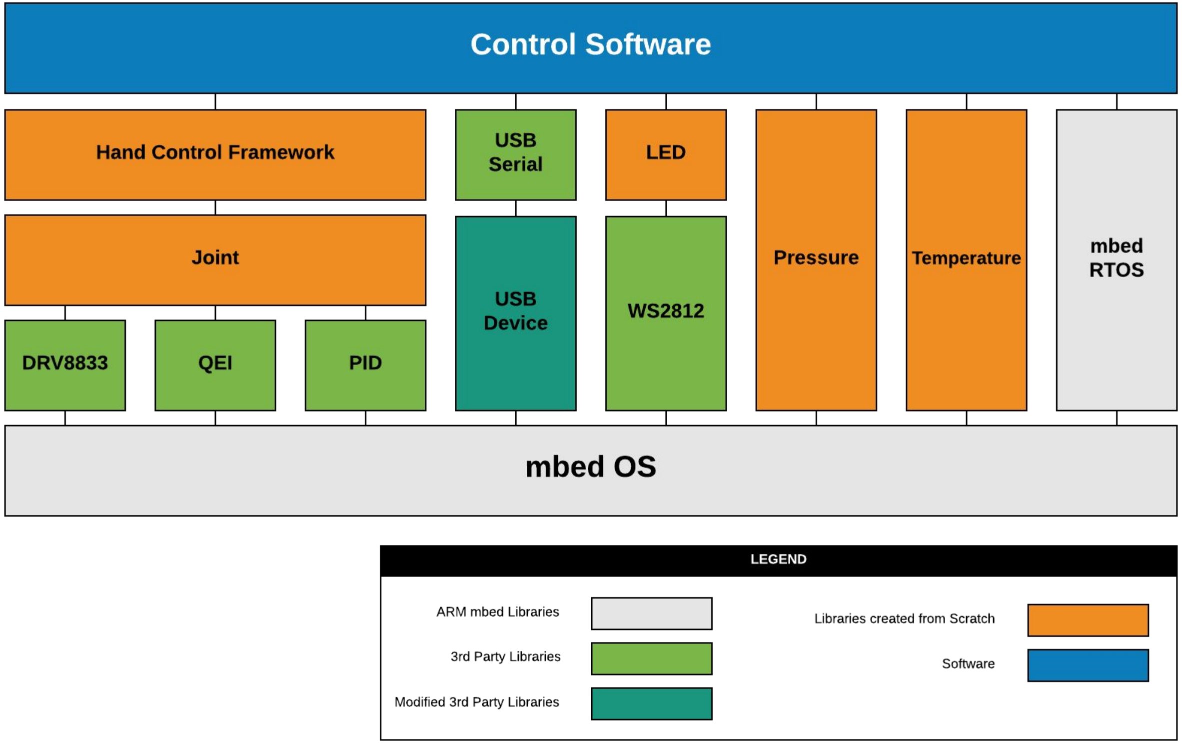
Program
Program.SchDoc
GND
+3V3
SWDIO
SWCLK
USB
USB.SchDoc
GND
USB_D1_N
USB_D1_P
EMG
EMG.SchDoc
GND
+3V3
SCL0
SDA0
Pressure
Pressure.SchDoc
GND
+3V3
SDA1
SCL1
Micro Controller
STM32F0.SchDoc
SWDIO
SWCLK
RESET_B
USB_D1_N
USB_D1_P
SCL0
SDA0
SCL1
SDA1
LED0
+3V3
GND
IDXENC[1..2]
MIDENC[1..2]
PKYENC[1..2]
RNGENC[1..2]
THAENC[1..2]
THBENC[1..2]
IDXPWM[1..2]
MIDPWM[1..2]
PKYPWM[1..2]
RNGPWM[1..2]
THAPWM[1..2]
THBPWM[1..2]
nSLEEP
Motor Drivers
MotorDrive.SchDoc
IDXPWM[1..2]
MIDPWM[1..2]
RNGPWM[1..2]
PKYPWM[1..2]
THAPWM[1..2]
THBPWM[1..2]
nSLEEP
RNG[1..2]
PKY[1..2]
THA[1..2]
THB[1..2]
MID[1..2]
IDX[1..2]
GND
VBAT
Motor Connectors
MotorCon.SchDoc
RNG[1..2]
PKY[1..2]
THA[1..2]
THB[1..2]
MID[1..2]
IDX[1..2]
THBENC[1..2]
THAENC[1..2]
RNGENC[1..2]
PKYENC[1..2]
MIDENC[1..2]
IDXENC[1..2]
GND
+3V3
LED
LED.SchDoc
LED0
+3V3
GND
Power
Power.SchDoc
VIN
+3V3
GND
VBAT

Schematics





*PWM = PWM where * is joint
*ENC = encoder where * is joint
LED0 = RGB status LED
nSLEEP = disable/enable motor drivers
USB_**** = USB data pins
SCL* & SDA* = I2C where * is channel



Software
Architecture

Goals:

- Modular and flexible
- Unit testable
- Heavily documented

Standards Cognizant:

- IEC 62304
- NASA's "The Power of Ten – Rules for Developing Safety Critical Code"

Software Architecture

- Implementation of Real Time Operating System (RTOS)
  - Multiple threads
  - Heavy preemption from Interrupt Service Routines (ISRs) for encoders
  - Watchdog thread for monitoring critical error conditions
- Custom USB Device library
- All libraries have documented APIs
- Reversible Design
  - No software changes needed between operating in left-hand or right-hand mode
  - Standard medical finger/digit numbering scheme used
- Extendable grasp framework

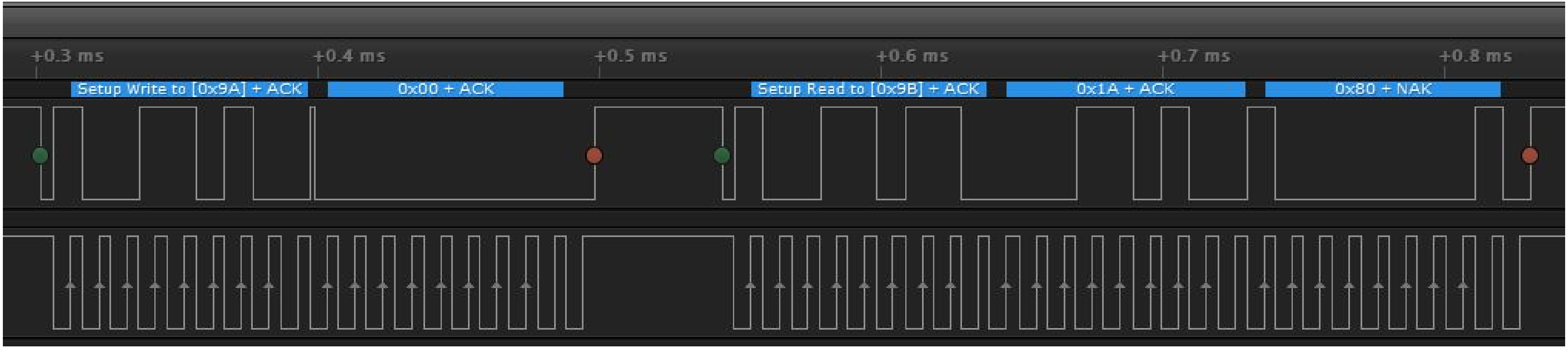
START

Microcontroller

20 Points

Requirement	Verification	Points
Output I2C Signal, Communicate with I2C	Verify with logic analyzer, Read data from I2C sensor	8
Interpret Sensor Data	Connect I2C sensor and stream output to serial console	6
Detect Rotor Movement & give relative position	Attach encoders and spin both ways, verify output position	6

I2C Protocol



Write Command

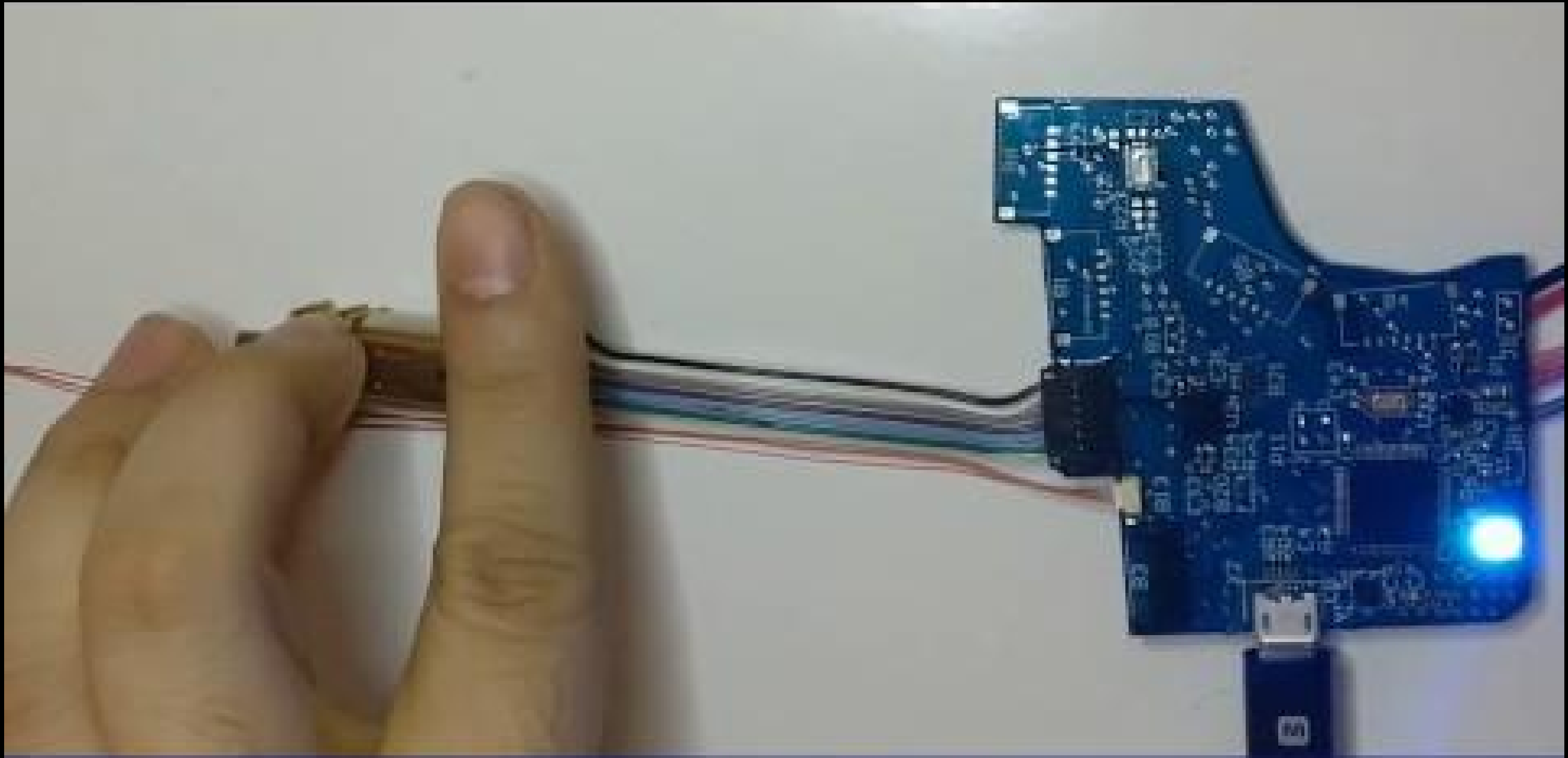
Telling temperature sensor to go to temperature register

Read Data

0x1A left shifted by 8 + 0x80 = 0x1A80

0x1A80 = 6784

6784/256 = 26.5 celsius

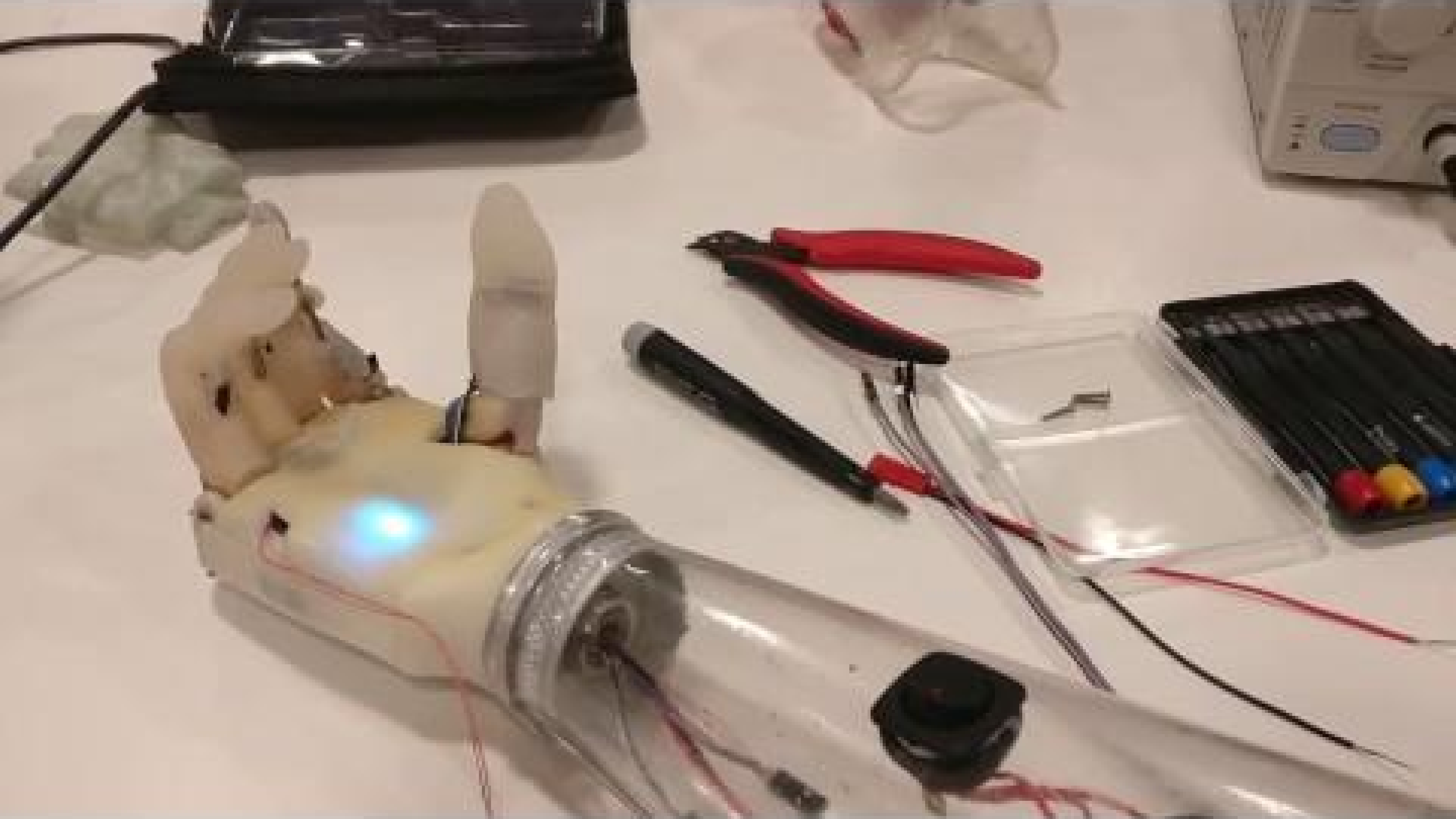


```
Temperature: 21    Pressure(raw): 3934857.000000    Pressure(hPa): 968.658447    Encoder Count: -6
Temperature: 21    Pressure(raw): 3934865.000000    Pressure(hPa): 968.660400    Encoder Count: -6
Temperature: 21    Pressure(raw): 3935025.000000    Pressure(hPa): 968.699463    Encoder Count: -6
Temperature: 21    Pressure(raw): 3934920.000000    Pressure(hPa): 968.673828    Encoder Count: -6
Temperature: 21    Pressure(raw): 3934922.000000    Pressure(hPa): 968.674316    Encoder Count: -6
Temperature: 21    Pressure(raw): 3935008.000000    Pressure(hPa): 968.695312    Encoder Count: -6
Temperature: 21    Pressure(raw): 3935126.000000    Pressure(hPa): 968.724121    Encoder Count: -6
Temperature: 21    Pressure(raw): 3935023.000000    Pressure(hPa): 968.698975    Encoder Count: -6
Temperature: 21    Pressure(raw): 3935017.000000    Pressure(hPa): 968.695312    Encoder Count: -6
Temperature: 21
```

Motor Controllers

15 Points

Requirement	Verification	Points
Command motor controllers via PWM	Verify motors can drive both forward and reverse	3.75
Improved connector resilience to improper use	Attempt various connections with incorrect orientations	3.75
Connector can withstand 1.5 Amp current	Setup test load and verify no damage after 30 seconds	3.75
Conformal coating present	Visually inspect surface	3.75

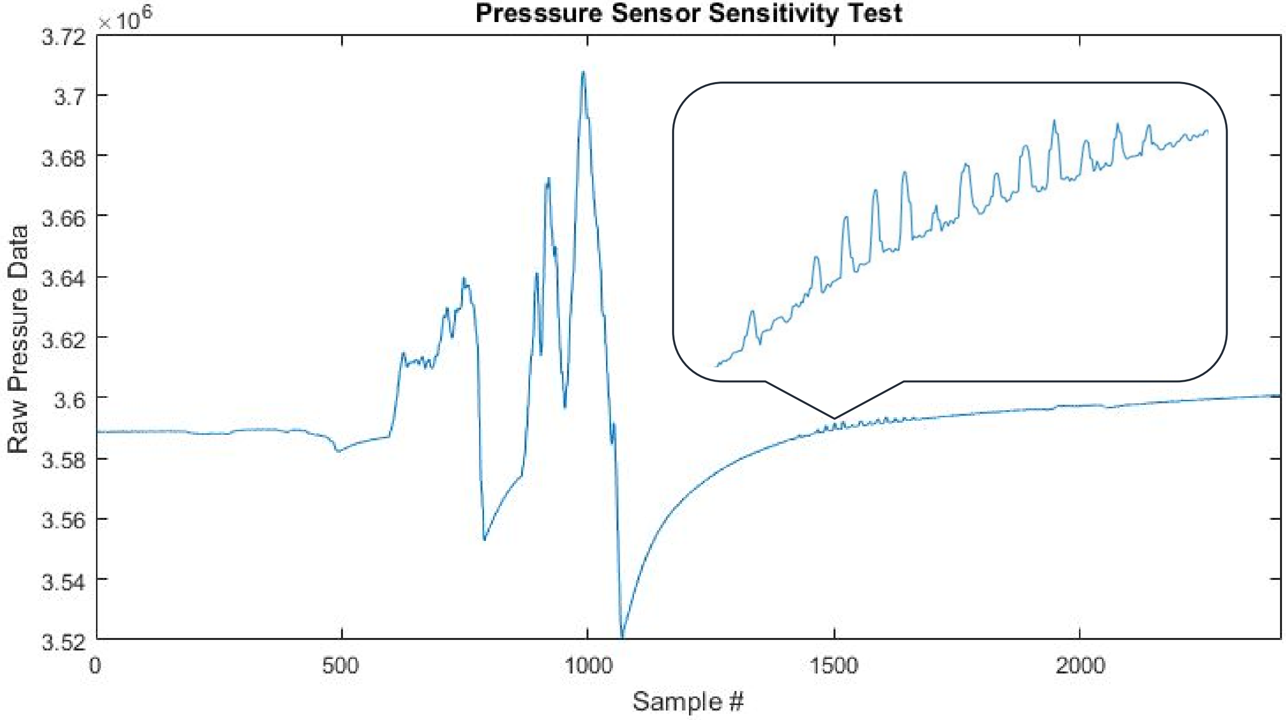


Pressure Sensors

7 Points

Requirement	Verification	Points
Communicate over I2C	Connect sensor and stream pressure value to serial console	7

```
Temperature: 24     Pressure(raw): 4320247.000000     Pressure(hPa): 1054.747803     Encoder Count: 0
Temperature: 24     Pressure(raw): 4335704.000000     Pressure(hPa): 1058.541016     Encoder Count: 0
Temperature: 24     Pressure(raw): 4365906.000000     Pressure(hPa): 1065.895020     Encoder Count: 0
Temperature: 24     Pressure(raw): 4401186.000000     Pressure(hPa): 1074.508301     Encoder Count: 0
Temperature: 24     Pressure(raw): 4426946.000000     Pressure(hPa): 1080.797363     Encoder Count: 0
Temperature: 24     Pressure(raw): 4440482.000000     Pressure(hPa): 1086.055176     Encoder Count: 0
Temperature: 24     Pressure(raw): 4479555.000000     Pressure(hPa): 1093.641357     Encoder Count: 0
Temperature: 24     Pressure(raw): 4487106.000000     Pressure(hPa): 1095.484863     Encoder Count: 0
Temperature: 24     Pressure(raw): 4488534.000000     Pressure(hPa): 1095.832486     Encoder Count: 0
Temperature: 24     Pressure(raw): 4493326.000000     Pressure(hPa): 1097.000977     Encoder Count: 0
Temperatur
```



Presssure Sensor Sensitivity Test
$\times 10^6$
3.72
3.7
3.68
3.66
3.64
3.62
3.6
3.58
3.56
3.54
3.52
Raw Pressure Data
0
500
1000
1500
2000
Sample #

Temperature Sensor

3 Points

Requirement	Verification	Points
Communicate over I2C	Stream output in °C to serial console	1
Has accuracy of ±1° C	Verify temperature reading with an external sensor	1
Simulate safety shutdown	Apply a heat gun to raise board temperature to 55° C and ensure: • LED turns red • Motors turn off	1

```
Temperature: 53    Pressure(raw): 4056254.000000    Pressure(hPa): [illegible]    Encoder Count: 1
Temperature: 53    Pressure(raw): 4056154.000000    Pressure(hPa): 900.271973    Encoder Count: 1
Temperature: 53    Pressure(raw): 4056208.000000    Pressure(hPa): 900.284668    Encoder Count: 1
Temperature: 53    Pressure(raw): 4056181.000000    Pressure(hPa): 900.278564    Encoder Count: 1
Temperature: 53    Pressure(raw): 4056269.000000    Pressure(hPa): 900.300049    Encoder Count: 1
Temperature: 53    Pressure(raw): 4056205.000000    Pressure(hPa): 900.284424    Encoder Count: 1
Temperature: 53    Pressure(raw): 4056299.000000    Pressure(hPa): 900.307373    Encoder Count: 1
Tempera
```

Status LED

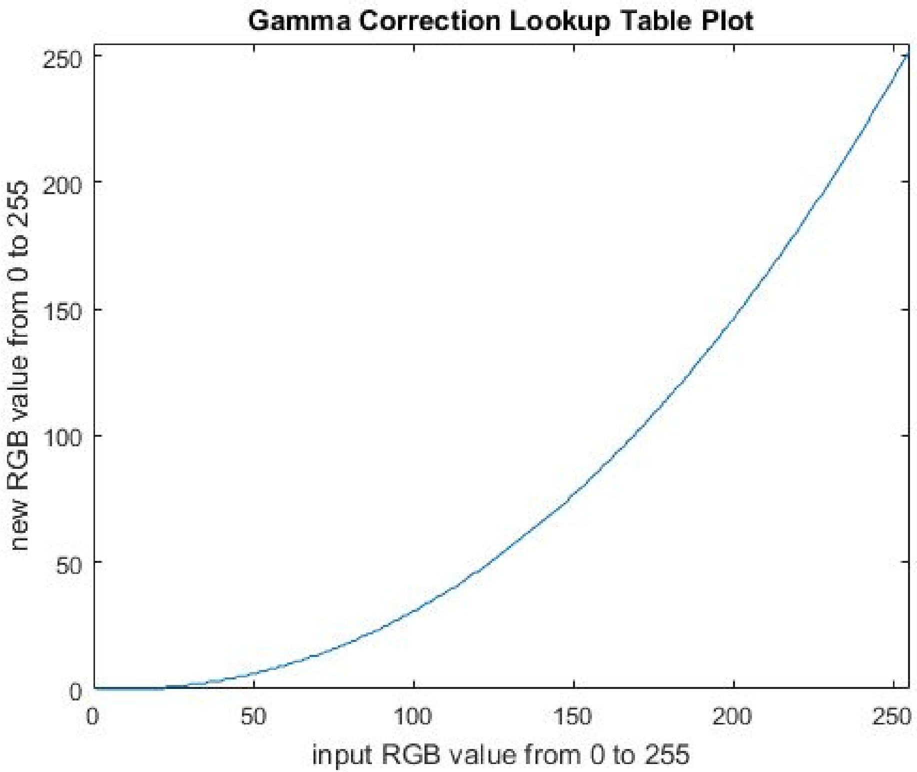
5 Points

FINISH

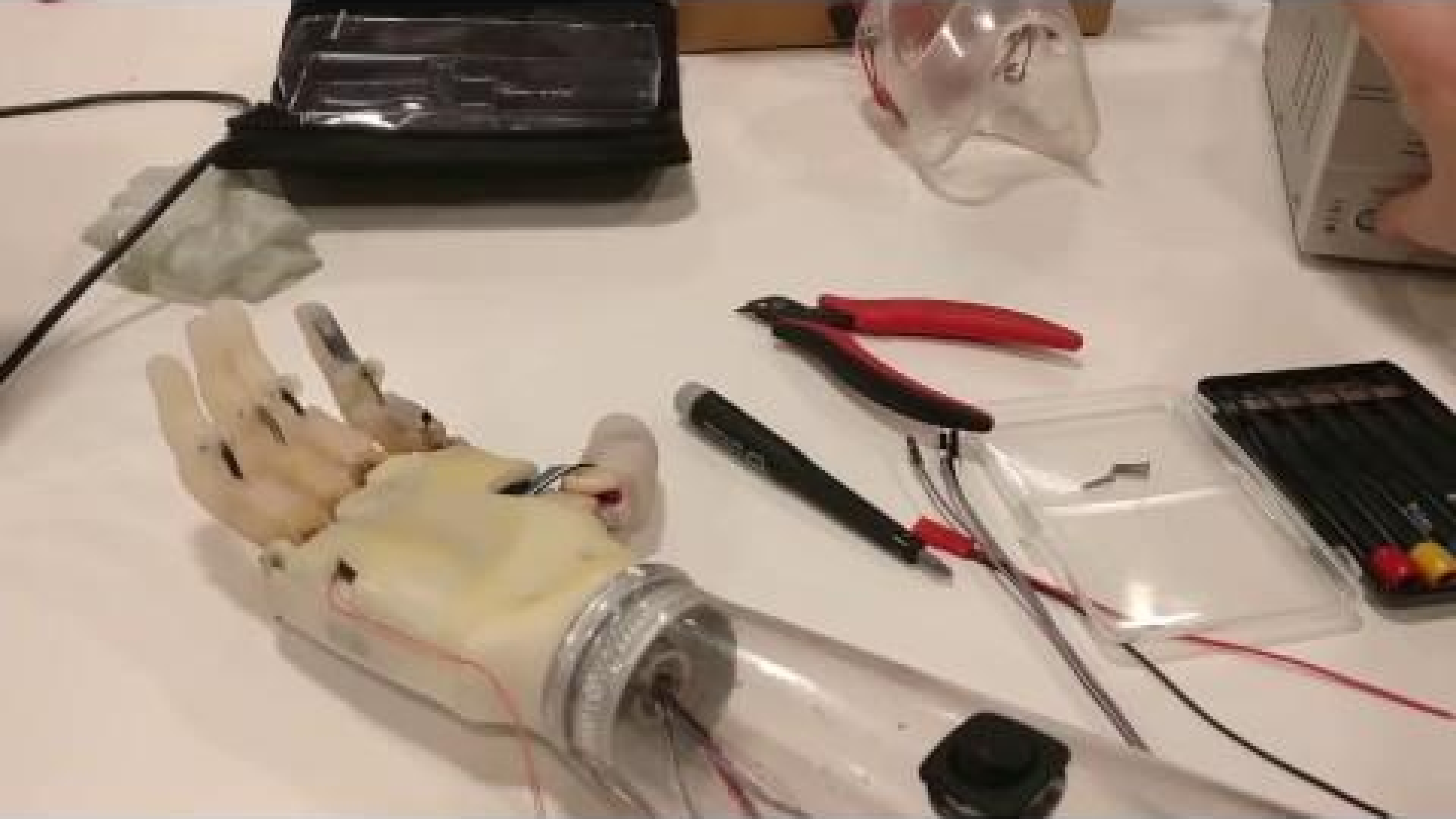
Requirement	Verification	Points
Communicate over PWM	Turn LED on and off via microcontroller command	2
Cycle through colors (white, red, green, blue)	Visually observe output from a demo program	2
Light viewable from a 90° viewing area 1 foot away	Verify color is viewable 45° off center from 1 foot distance	1

Gamma Correction helps the LED have a more visually accurate representation of true color.

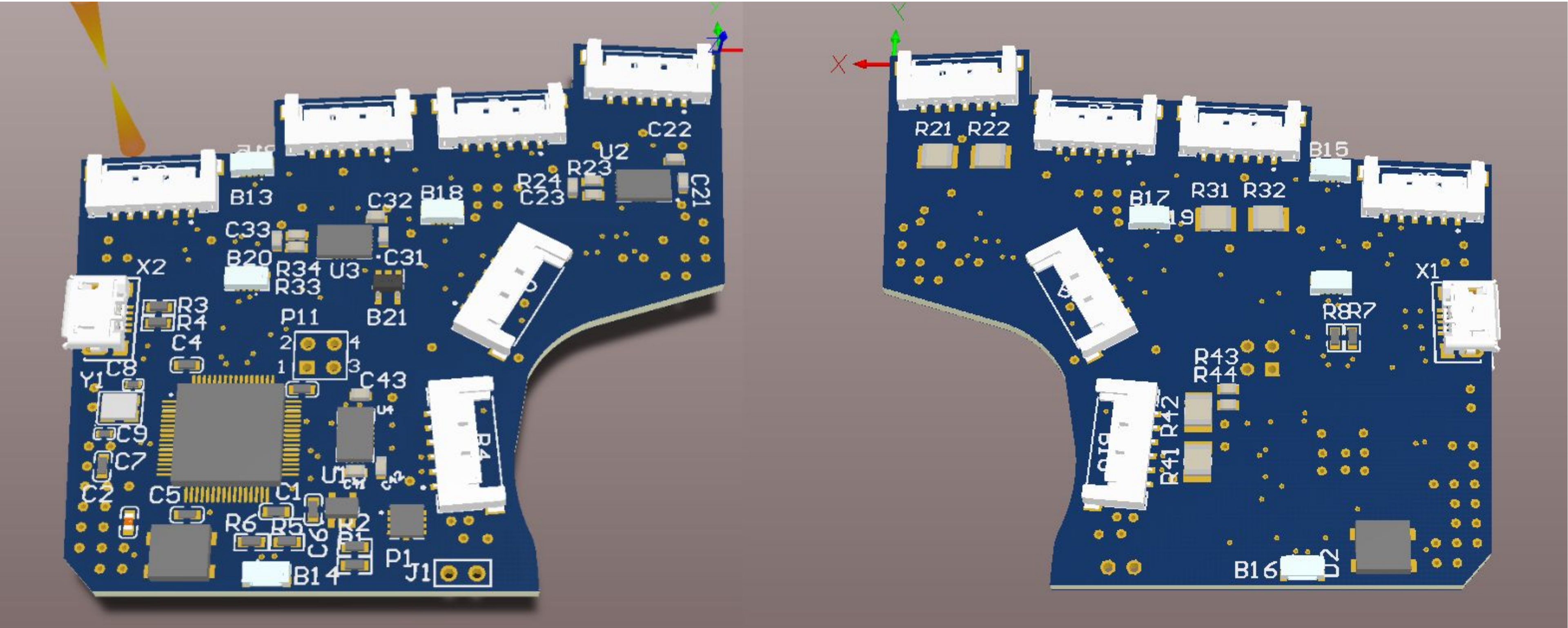
The **Natural Color System** (NCS) was used for all visual indicators to ensure usability across the world.



data courtesy of rgb-123.com

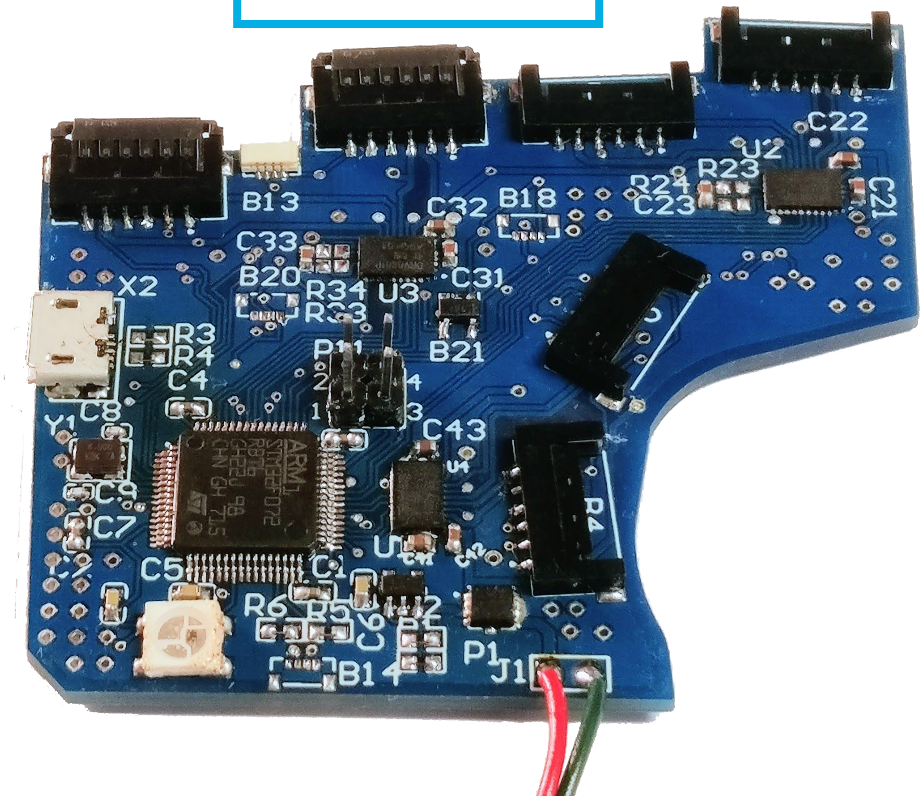


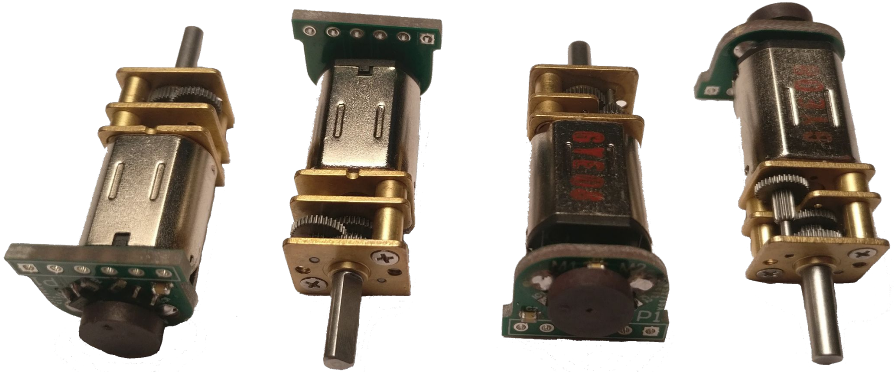
3D
Rendering



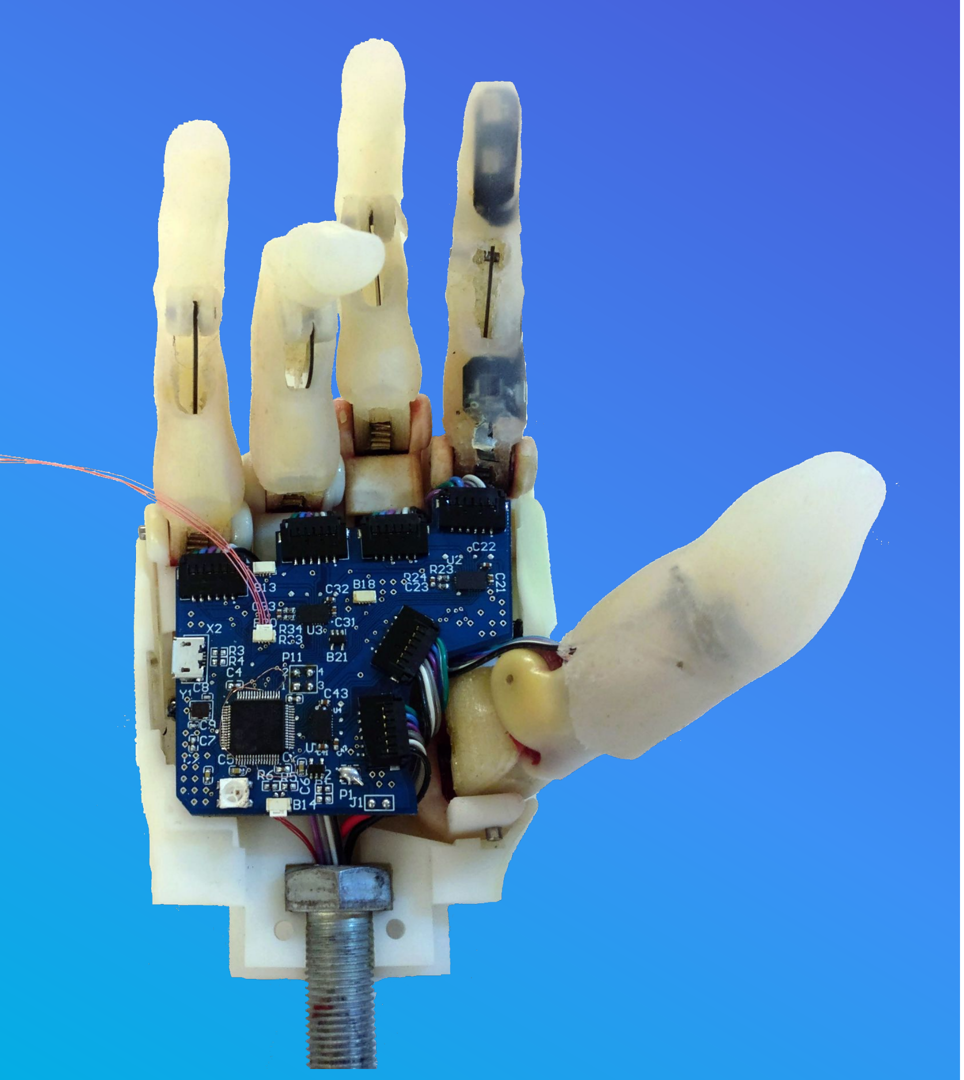
Soldered Circuit Boards

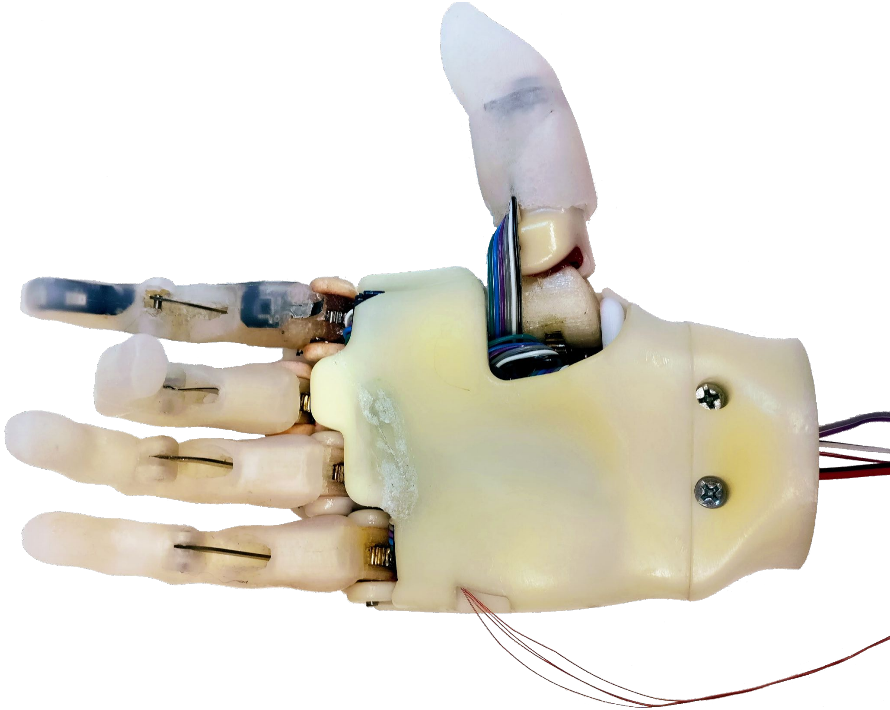
Hand PCB





Motors / Encoders

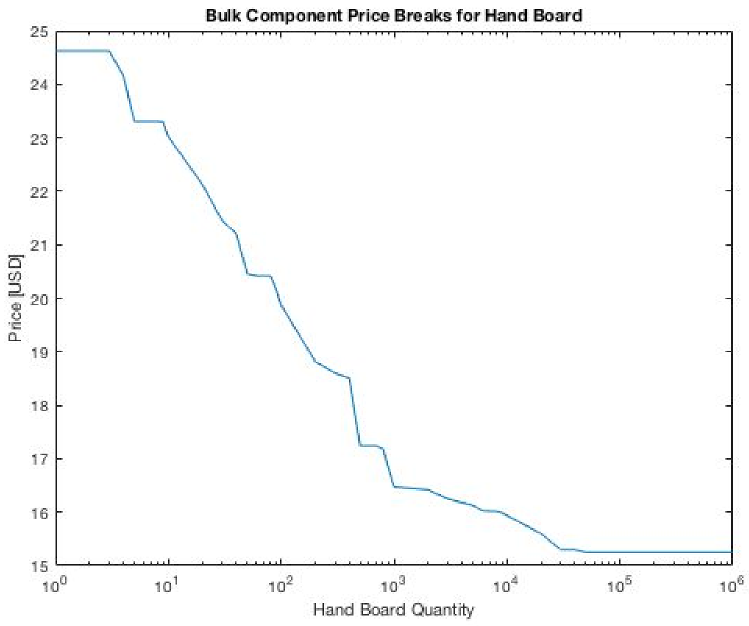




Assembled

Prosthetic Hand

Cost
breakdown



Cost reduces when buying components in bulk

Estimated total project labor cost: $67,200

Estimated project materials cost: $58

Total prototype development cost: $67,258

For the hand board...

$21.20

Components Cost

Price based on bulk price breaks from reputable dealers

Data courtesy of octopart.com

$9.85

Board & Assembly Cost

Board and assembly cost for 40 boards from PCBWay with kitted / cosigned components

$31.05

Total Hand Board Cost

Total combined hand control board price, fully produced, assembled, tested and shipped.

Standards

& Regulatory Compliance

- PSYONIC prosthetic hand is slated for FDA approval
- Several industry standard compliance guidelines need to be met for fast-tracking FDA processes
- Our project kept three main guidelines in mind
- Best practices drove every engineering decision
  - Extensive ground plane usage
  - Insulation resistance testing
  - Application of urethane conformal coating

01

IEC 62304

Medical Device Software

02

IEC 62353

Medical Electrical Equipment,
General Requirements for Safety

03

UL94 V-1

Flammability Standard

Retrospective

Learning Curves

- Neither of us had much, if any, embedded programming experience
- This was the first time we have had PCBs manufactured

Difficulties & Hurdles

- USB Device libraries were previously non-existent for our microcontroller
- The STM32 interrupt handler proved inflexible and difficult to work with
- Difficulty in soldering various small packaged devices and confirming good connections

Future
Work

This project *will* continue.

In order to make it viable, a few modifications need to be made for the next revision.

BLDC Motors
Implement brushless DC (BLDC) motor control in order to provide greater speed and torque.

Back EMF
Use back EMF instead of quadrature encoders to gain better velocity estimation.

EMG Systems
Integrate with Coapt's off the shelf electromyography (EMG) system.

Certification
Verify compliance with 3rd party certification bodies, such as UL or CE.

image courtesy of Psyonic