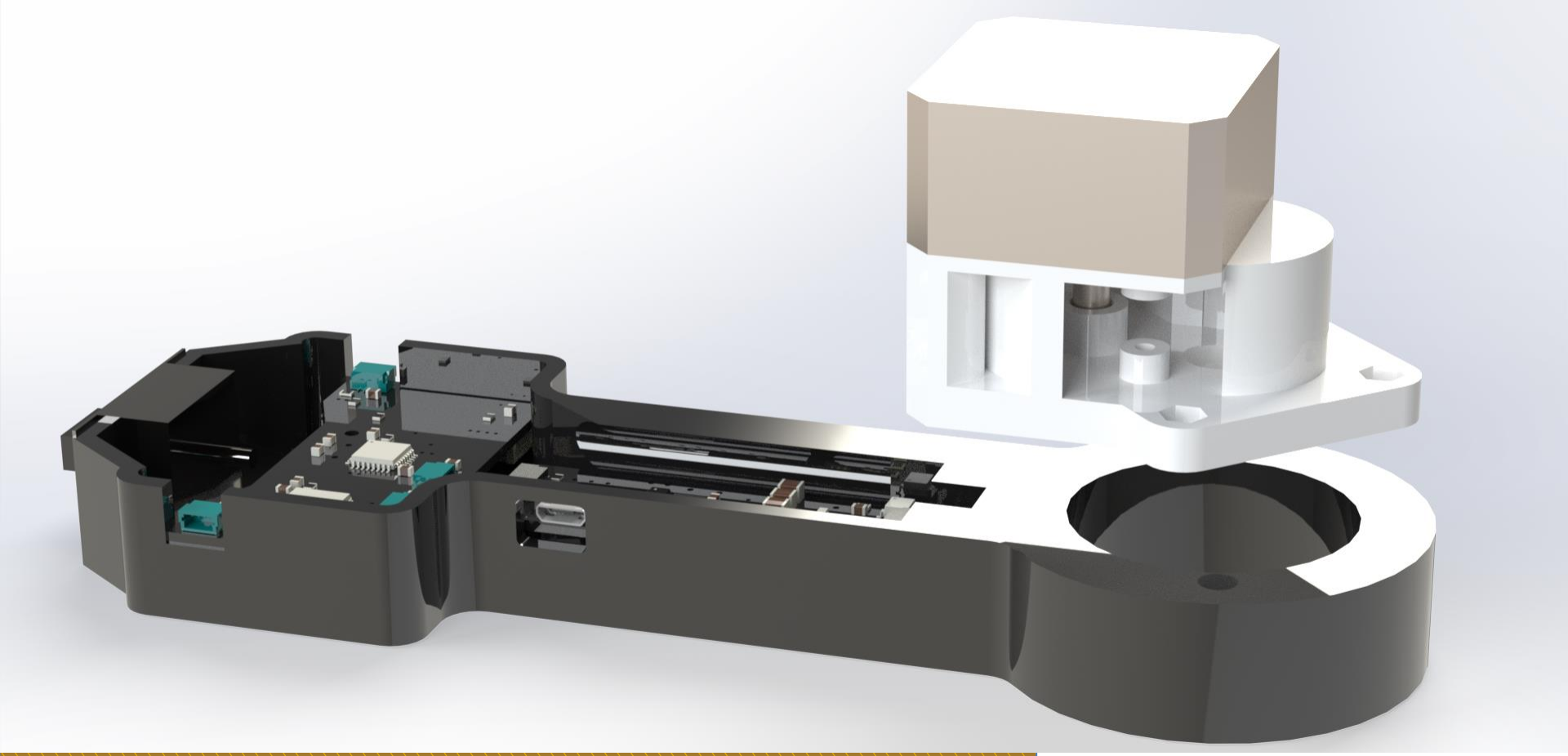


ECE477 MIDTERM DESIGN REVIEW: TEAM 6

PURDUE
UNIVERSITY

OUTLINE

- Project Overview
- Major Components
- Block Diagram
- Packaging Design
- HBmS Schematic and Layout
- DAqS Schematic and Layout
- Prototyping Progress
- Software Development Status
- Project Timeline
- Questions

PURDUE
UNIVERSITY

PROJECT OVERVIEW

REVEX: A NON-OPTICAL VR TRACKING SOLUTION

- Better Immersion
  - Immune to occlusion
  - Less obstruction
  - Haptic Feedback
- More Affordable
  - Cheaper materials
  - Fewer sensors
- More Efficient
  - Low-power, BLE
  - Energy Harvesting

Rokoko Motion Capture Suit
https://www.rokoko.com/products/smartsuit-pro

PURDUE UNIVERSITY

PSSCS

PROJECT SPECIFIC SUCCESS CRITERIA

- **PSSC #1**: Ability to read accelerometer and gyroscope data from an inertial measurement unit (IMU).
- **PSSC #2**: Ability to read voltage from an analog potentiometer to infer elbow joint angle using an Analog-Digital Converter (ADC).
- **PSSC #3**: Ability to transceive raw sensor data and haptic feedback intensity value bi-directionally between the wearable device and host computer via Bluetooth Low Energy (BLE).
- **PSSC #4**: Ability to provide passive haptic feedback on an elbow joint by variably shorting motor coils.
- **PSSC #5**: Ability to estimate arm position in a virtual reality (VR) simulation on the host computer by fusing acceleration, gyroscope, and VR headset position/orientation.

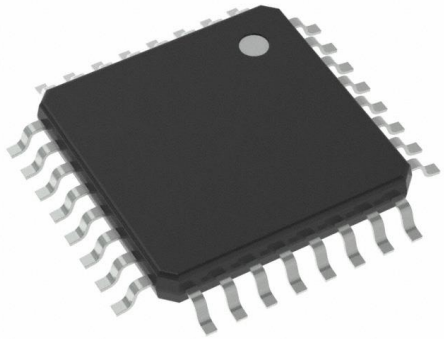
PURDUE
UNIVERSITY

MAJOR COMPONENTS

MAJOR COMPONENTS

MICROCONTROLLER

- Possible Options
  - STM32L081KZT
  - STM32F030R8
  - STM32F031K6T7
- Selected Choice
  - **STM32L081KZT**
- Reasoning for Choice
  - Low-power
  - Large Flash
  - Pin Count
  - Available Features
  - Required Supply Voltage



Chip	Bus Width	CLK Speed	Timers	SRAM	Flash	Power Consumption	Cost
STM32L081KZT [13]	32	32 MHz	6	20 KB	192 KB	87 uA/MHz	$6.07
STM32F030R8 [11]	32	48 MHz	7	8 KB	64 KB	250 uA/MHz	$10.99
STM32F031K6T7 [12]	32	48 MHz	9	4 KB	32 KB	110 uA/MHz	$4.31

PURDUE UNIVERSITY

MAJOR COMPONENTS

INERTIAL MEASUREMENT UNIT

- Possible Options
  - BHI160B
  - ICM-20948
  - BNO055
- Selected Choice
  - **ICM-20948**
- Reasoning for Choice
  - Availability
  - Low-power
  - SPI/High Frequency Sampling
  - Footprint
  - Supply Voltage
  - 9DOF (Magnetometer)

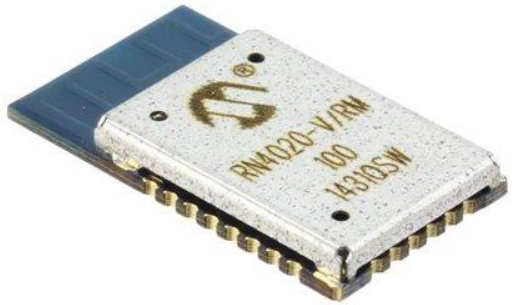
Chip	DOF	Supply Voltage, Total Power	Market Availability	Footprint	Comms Protocol	Cost
BHI160B [2]	6[2]	1.8 V, 2.8 mW	Great	Bad[3] (BGA)	I2C	$6.71
ICM-20948 [5]	9[4]	1.8 V, 2.5 mW	Only Boards in Stock	Great (QFN)	SPI, I2C	$16.95*
BNO055 [1]	9	2.5 V (Analog), 31 mW	Only Boards in Stock (Limited)	Ok (LGA)	I2C, UART	$40.00*

PURDUE UNIVERSITY

MAJOR COMPONENTS

BLUETOOTH MODULE

- Possible Options
  - CC2640
  - RN4020
  - 7B7412-00
- Selected Choice
  - **RN4020**
- Reasoning for Choice
  - Availability
  - Documentation
  - Low Powered
  - MLDP Mode

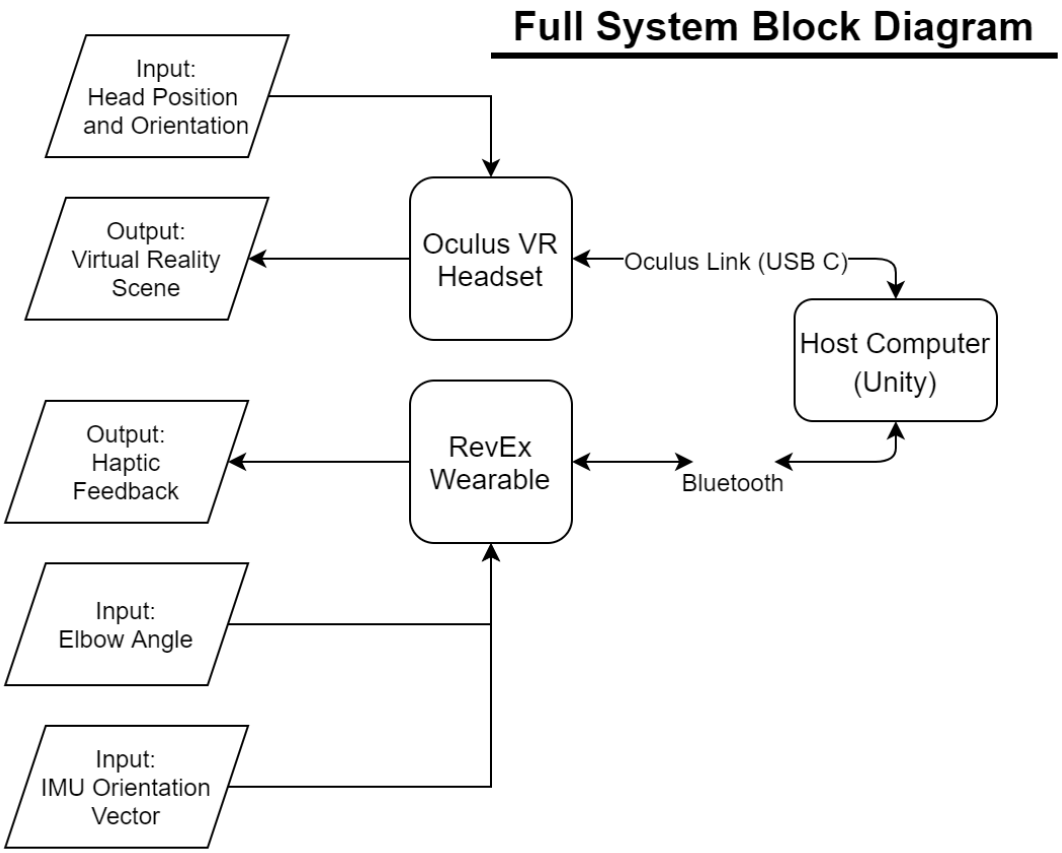


Module	Market Availability	FF	Transmit Power	Active Current	Sleep Current	Cost
CC2640 [14]	Low/None	7 x 7 mm	5 dBm	9.1 mA	1.4 uA	$6.49
nRF5340 [8]	Low	4.4 x 4 mm	3 dBm	5.3 mA	2.3 uA	$7.87
ZB7412-00 [15]	Great	16.9 x 11 mm	5 dBm	9.4 mA	1.6 uA	$9.86
RN4020	Good	195.5 x 11.5 mm	5 dBm	10.2 mA	1.4 uA	$8.67

PURDUE UNIVERSITY

BLOCK DIAGRAM

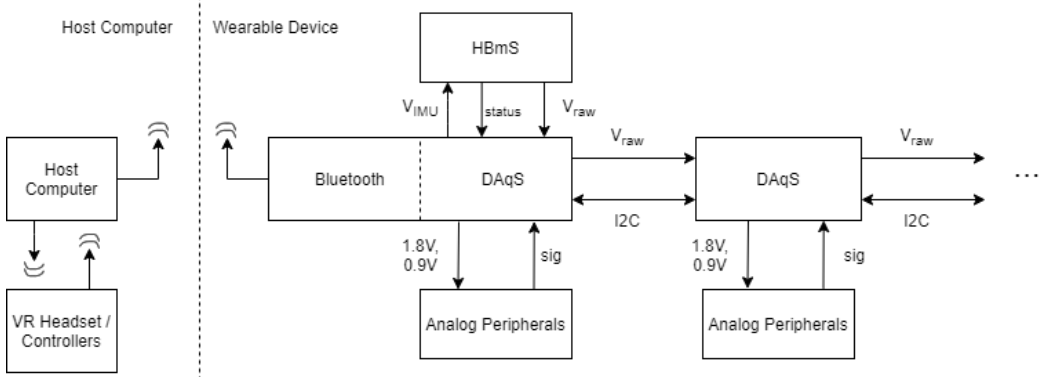
FULL SYSTEM



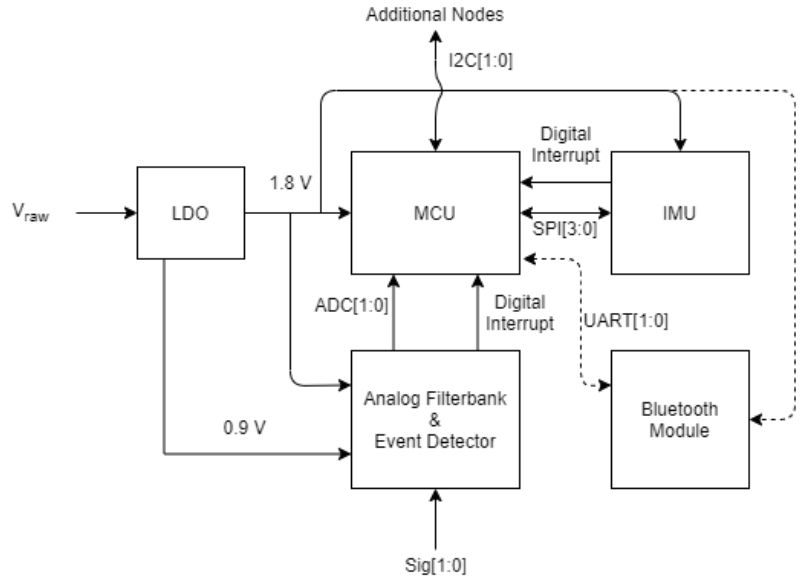
PURDUE
UNIVERSITY

BLOCK DIAGRAM

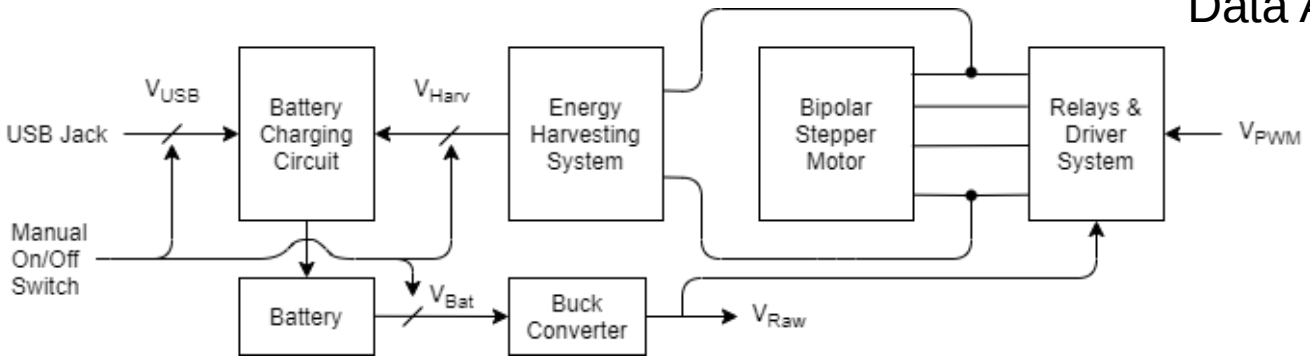
HARDWARE



Internodal Signal/Energy Flow



Data Acquisition System (DAqS)

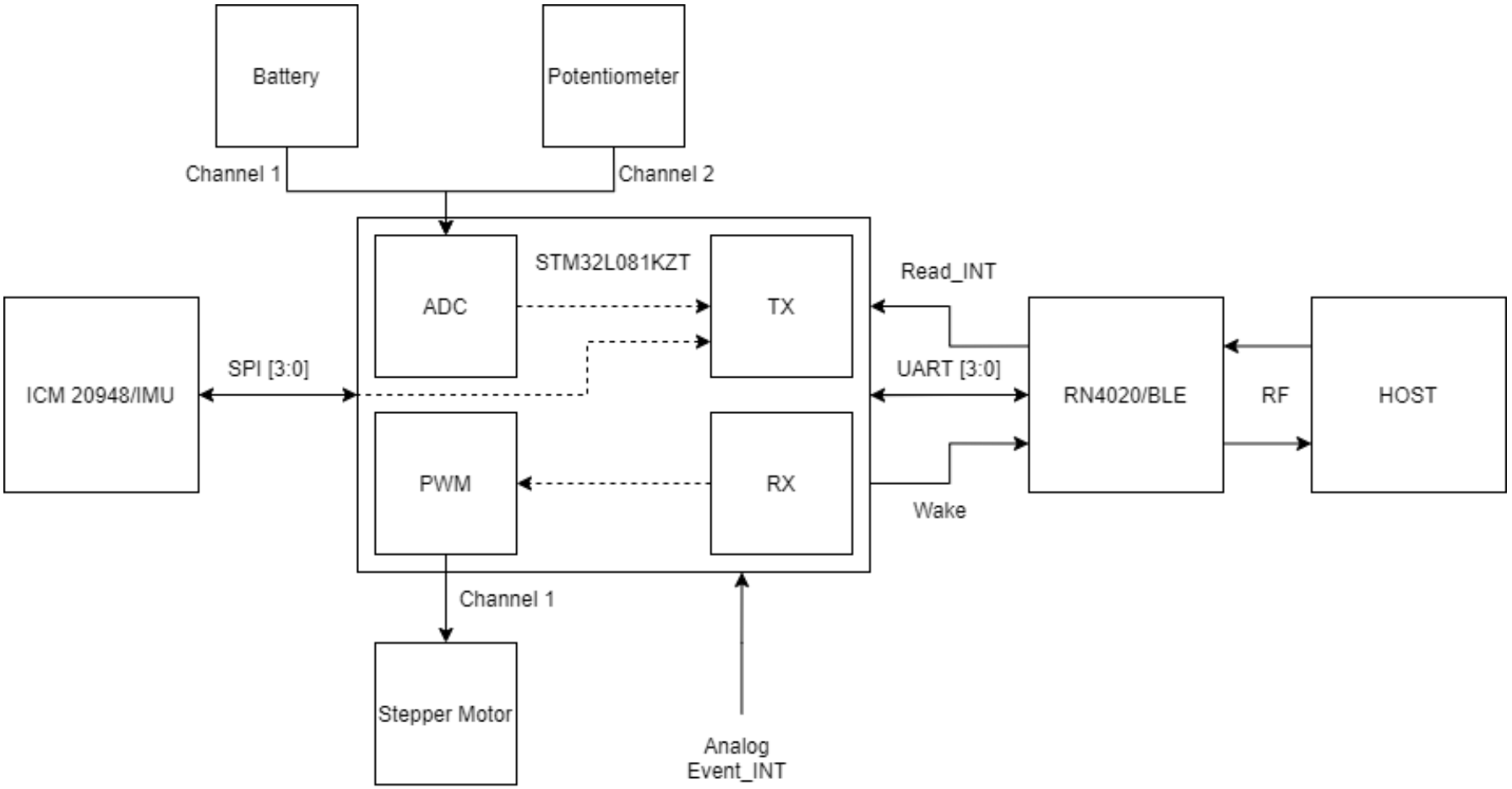


Haptics and Battery-management System (HBmS)

PURDUE UNIVERSITY

BLOCK DIAGRAM

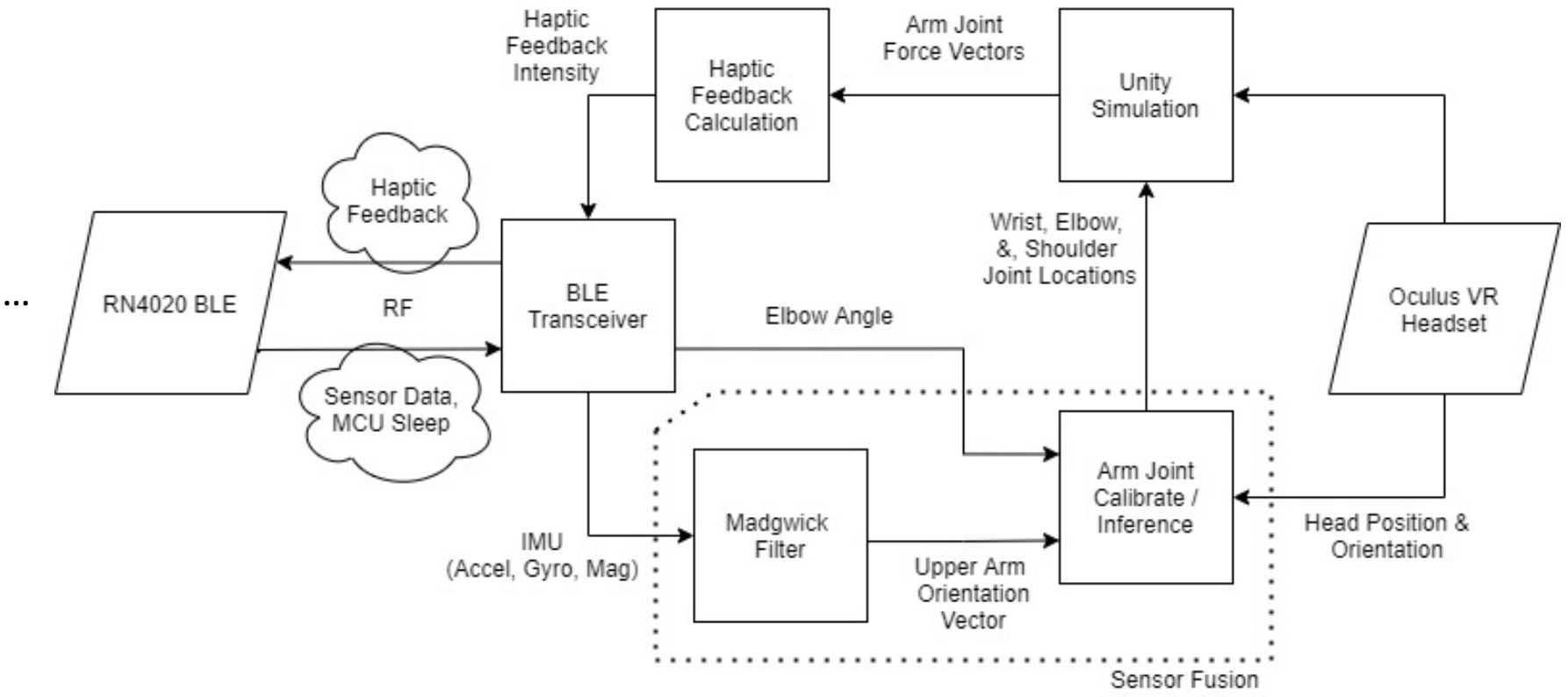
EMBEDDED SOFTWARE



PURDUE
UNIVERSITY

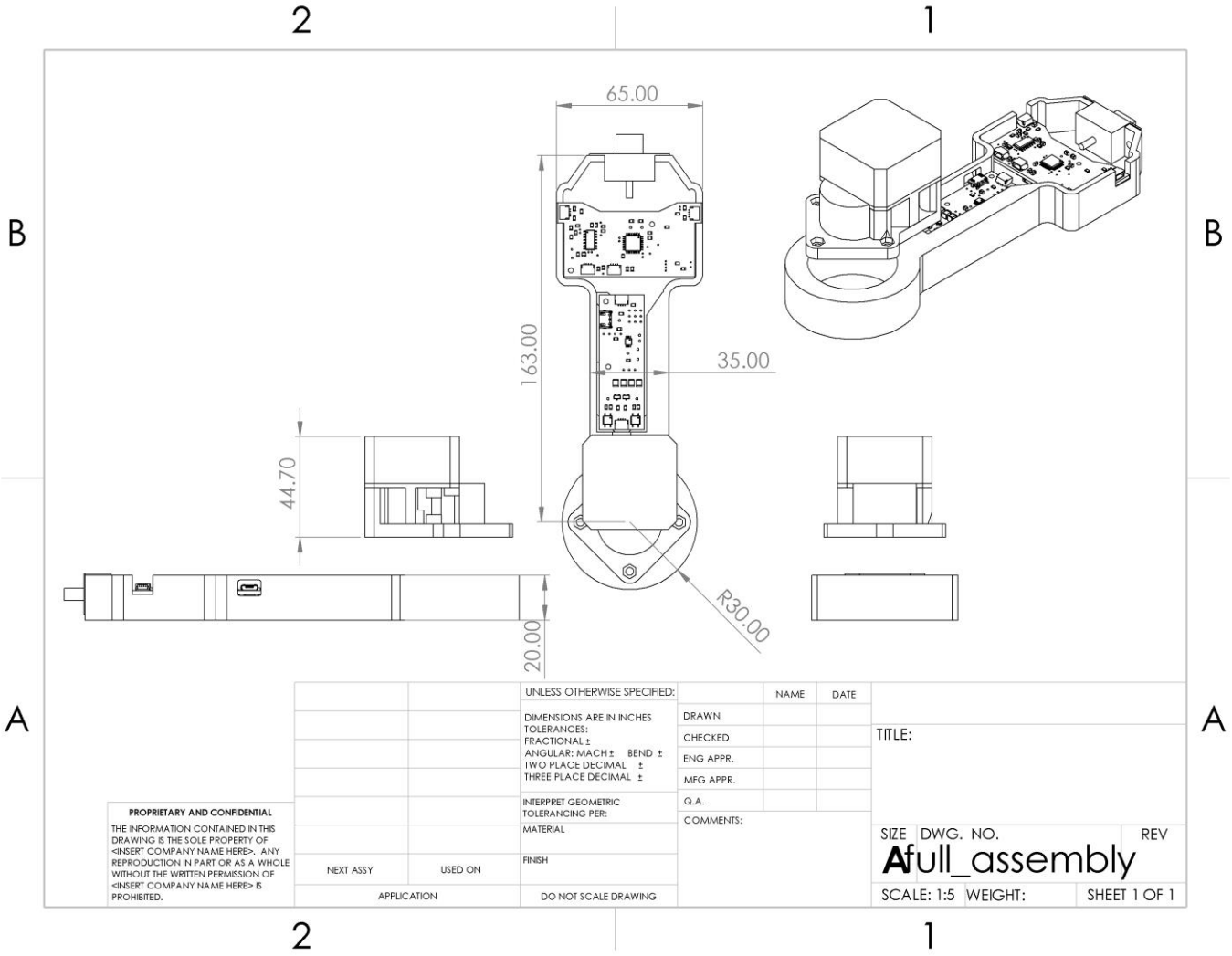
BLOCK DIAGRAM

HOST SOFTWARE



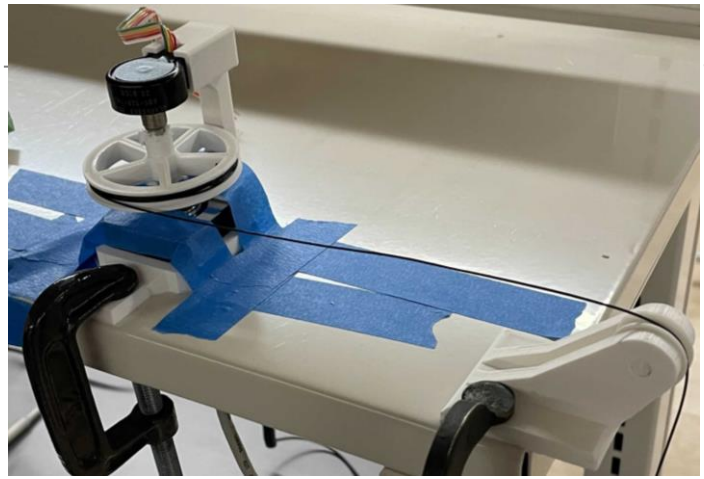
PURDUE UNIVERSITY

PACKAGING DESIGN



PURDUE UNIVERSITY

HBMS THEORY



$$\tau_m(s) = N^2 \beta s \theta; \quad \textbf{Viscous Coeff:} \quad \beta \approx b + \frac{{k_m}^2}{sL + ((R_{Phase} + R_{On})/D)}$$

θ: Rotation angle

N: Gear reduction ratio

b: Inherent (open-circuit) viscous damping

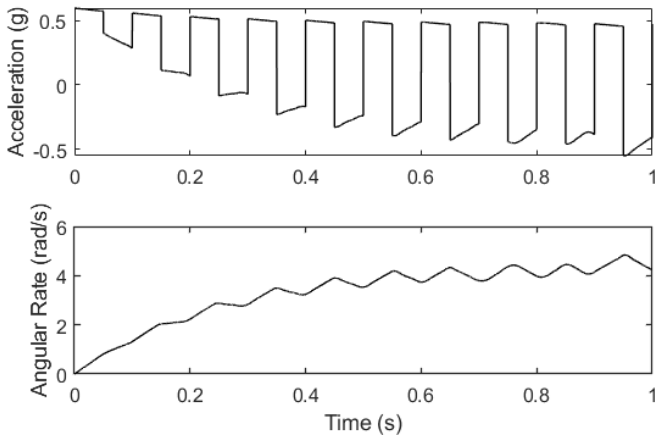
k_m: Motor torque constant

L: Motor phase inductance (can be neglected)

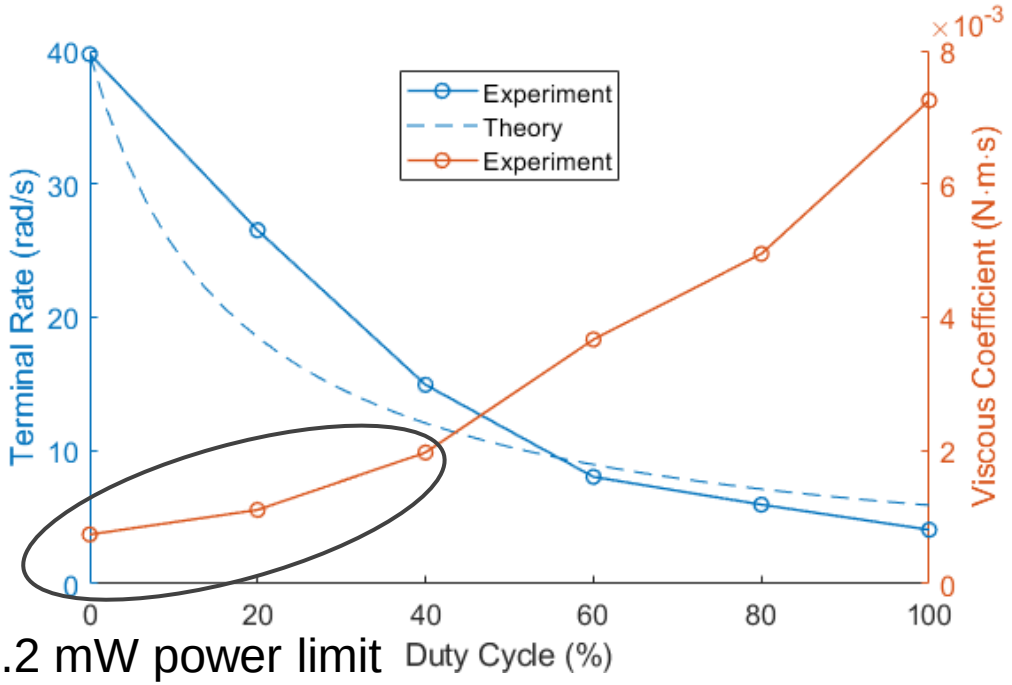
R_{Phase}: Phase resistance of the motor

R_{On}: On resistance of the solid-state relays

D: Optoelectronic relay duty cycle



Energy harvesting circuit was measured to have $\eta \approx 0.7\%$

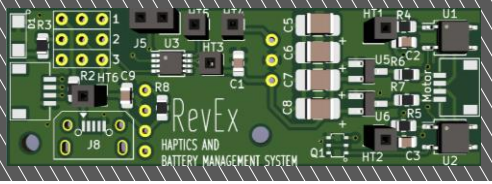


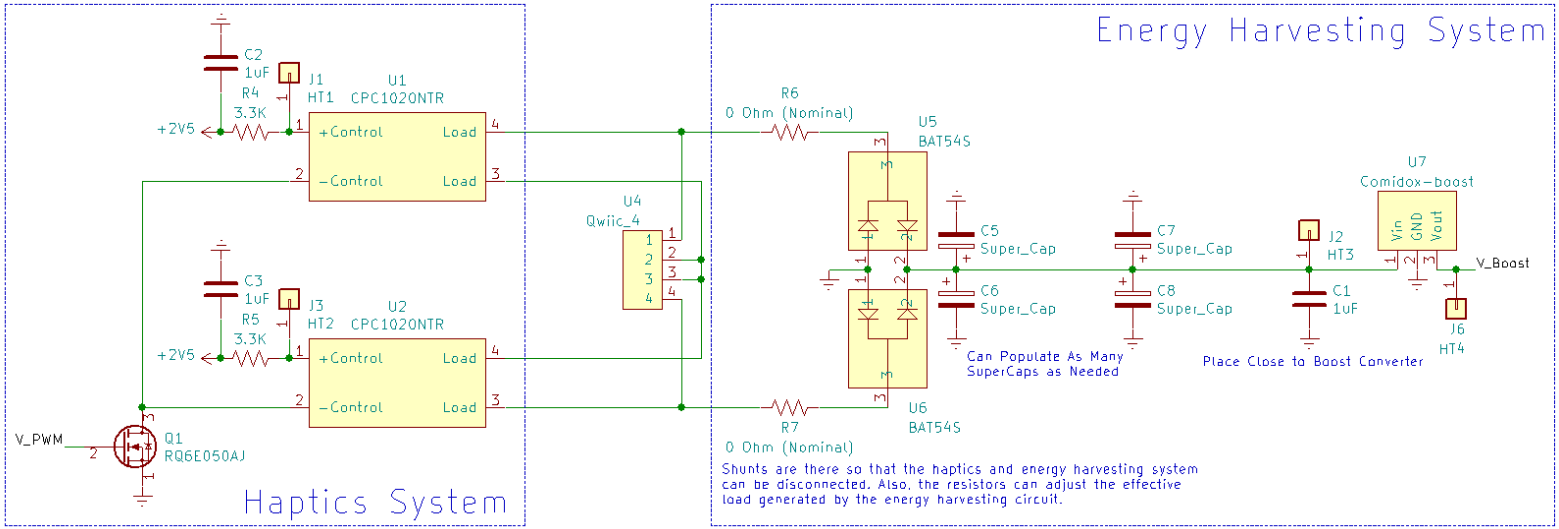
Saturation due to 2.2 mW power limit

PURDUE UNIVERSITY

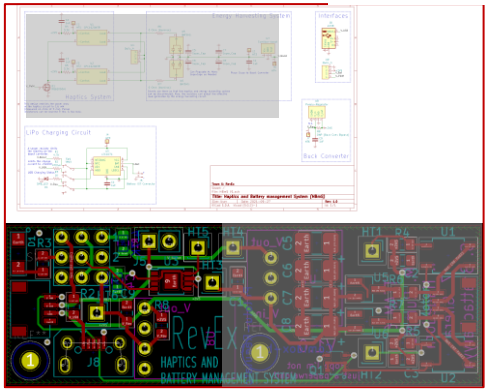
HBMS SCHEMATIC & LAYOUT

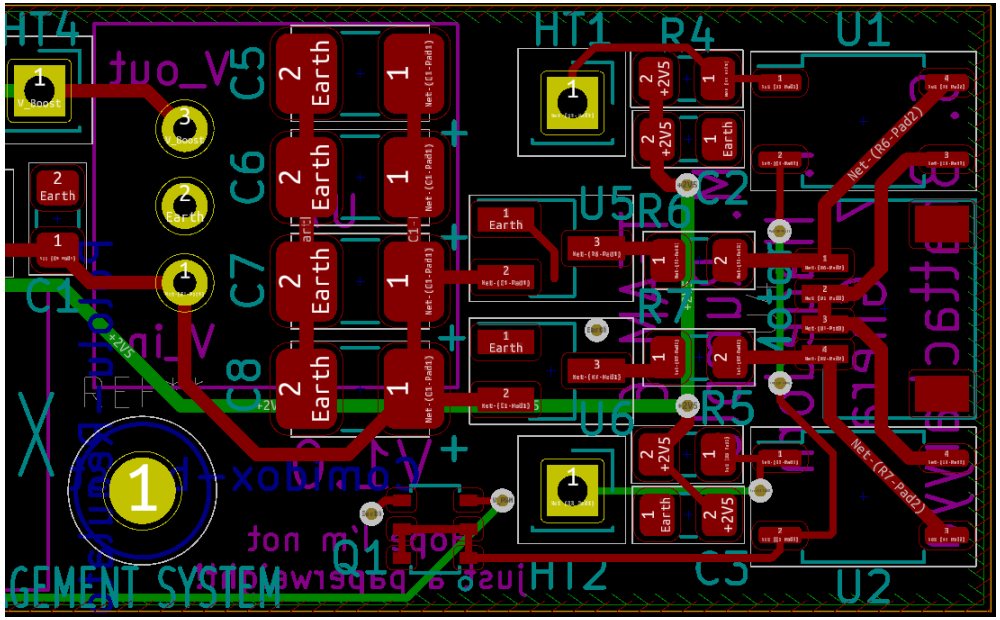
HAPTICS AND ENERGY HARVESTING SYSTEM





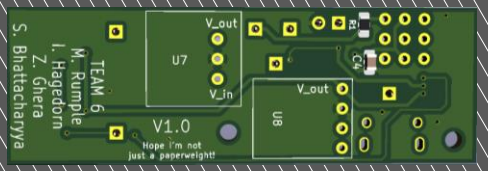
This design restricts the power draw of the haptics circuit to 1.6 mW (measured on-time of 3 ms). Pullup resistances can be lowered if this is too slow.



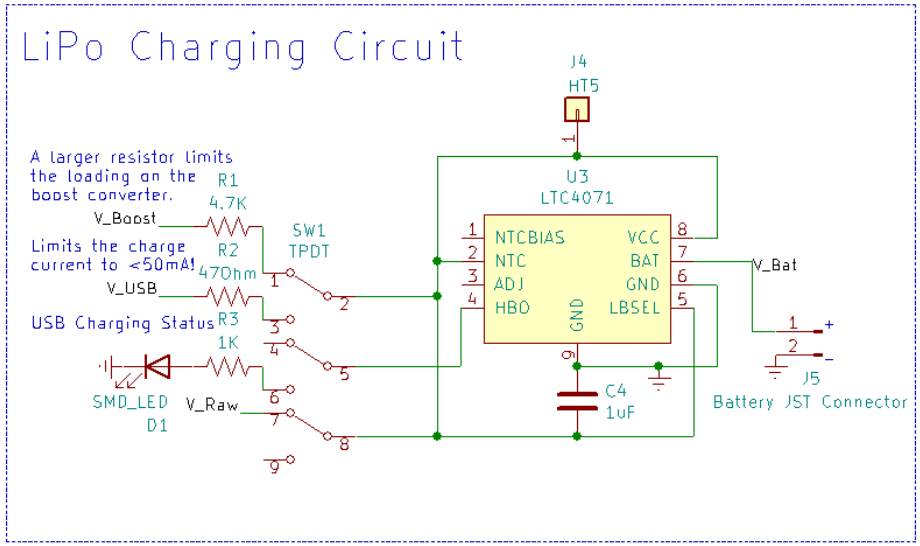


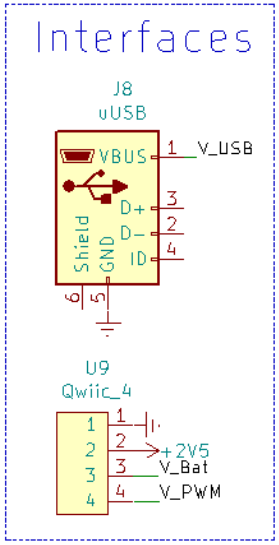
PURDUE UNIVERSITY

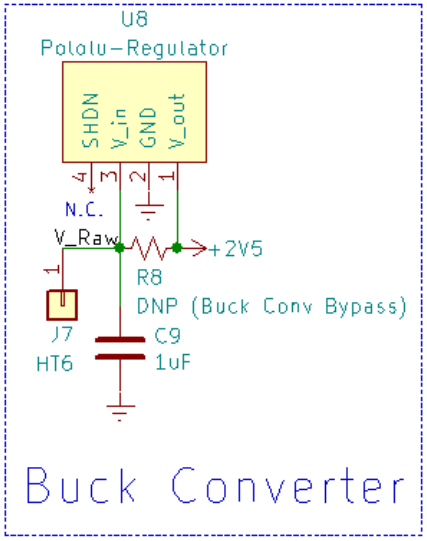
HBMS SCHEMATIC & LAYOUT

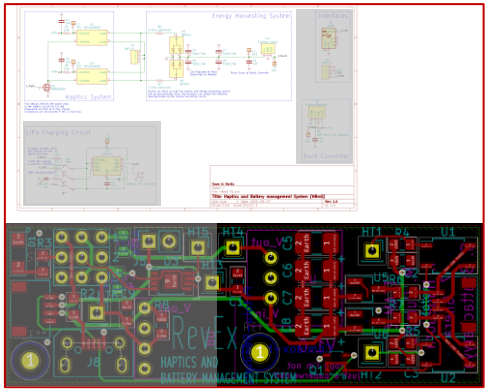


BATTERY MANAGEMENT, INTERFACES, BUCK CONVERTER

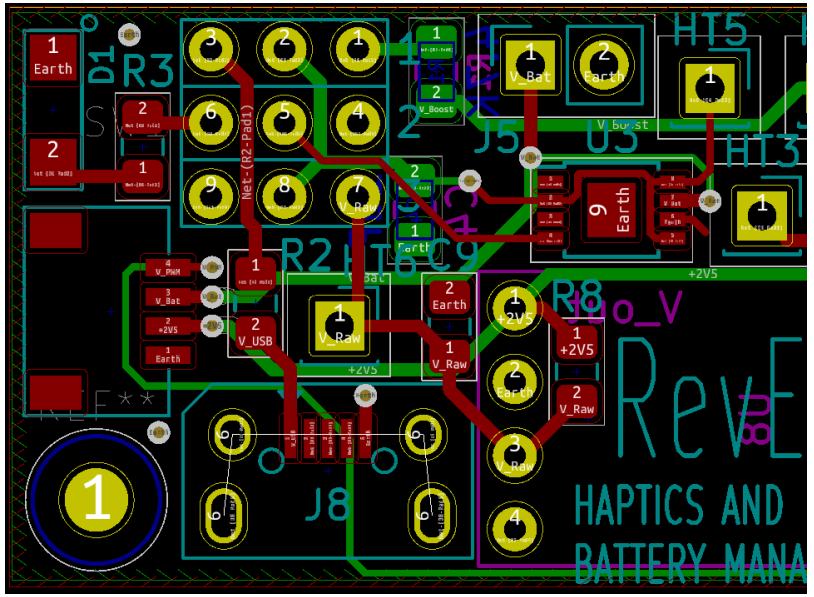








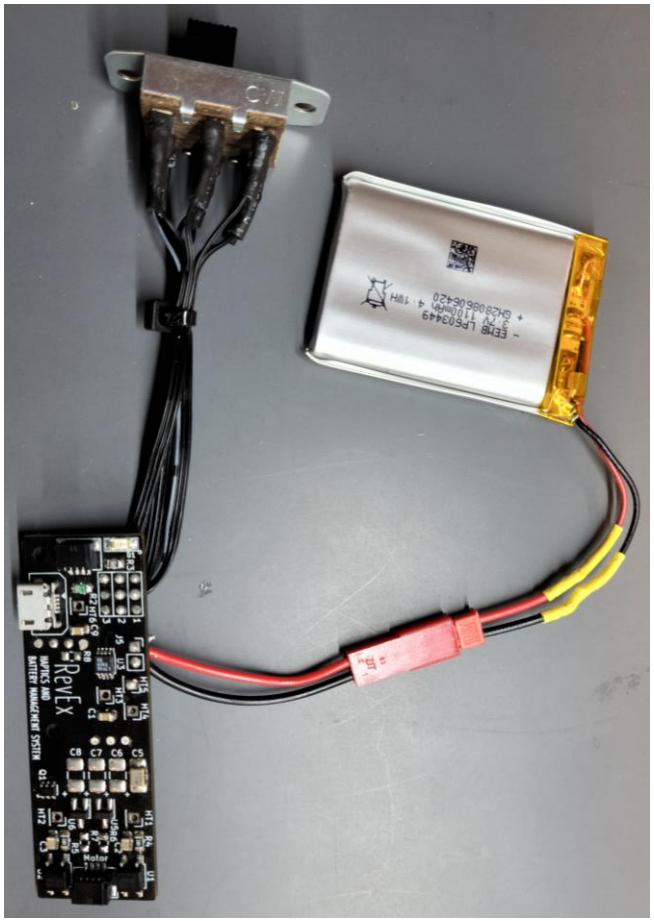
- Mechanical switch for simplicity in the first iteration. This may change.
- Buck Converter will reduce the TDP of the LDO by ~2.4x



PURDUE UNIVERSITY

HBmS: A REALITY CHECK

ISSUES ENCOUNTERED SO FAR WITH HBMS…

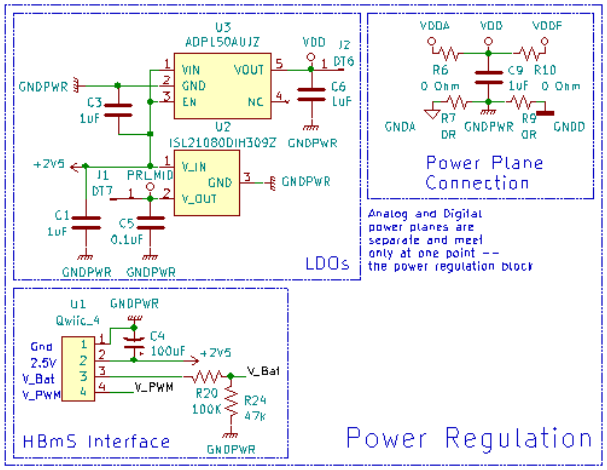


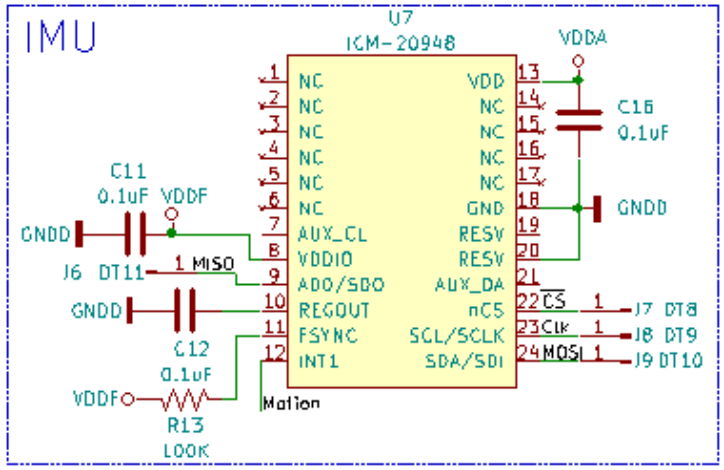
- Have populated & began HBmS testing
  - Serves as footprint verification…
- Energy harvesting circuit can create unintentional haptic feedback
  - Can be mitigated by tuning R6, R7
- LiPo charger is displaying strange behavior
  - Our chip isolates the battery
  - VDD and V_Bat on the LTC4071 must be momentarily connected on startup (they will then remain connected)
- Our stepper motor now skips when we apply haptic feedback
  - Possible lubricant leak?
  - Plan to replace motor and do failure analysis

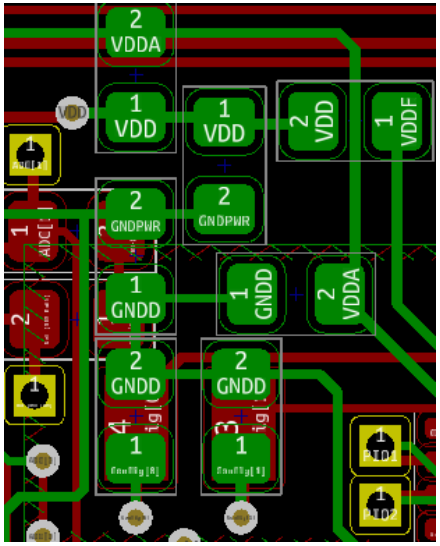
PURDUE UNIVERSITY

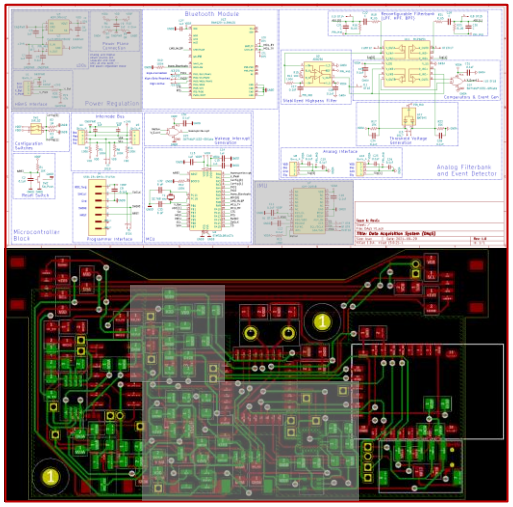
DAoS SCHEMATIC & LAYOUT

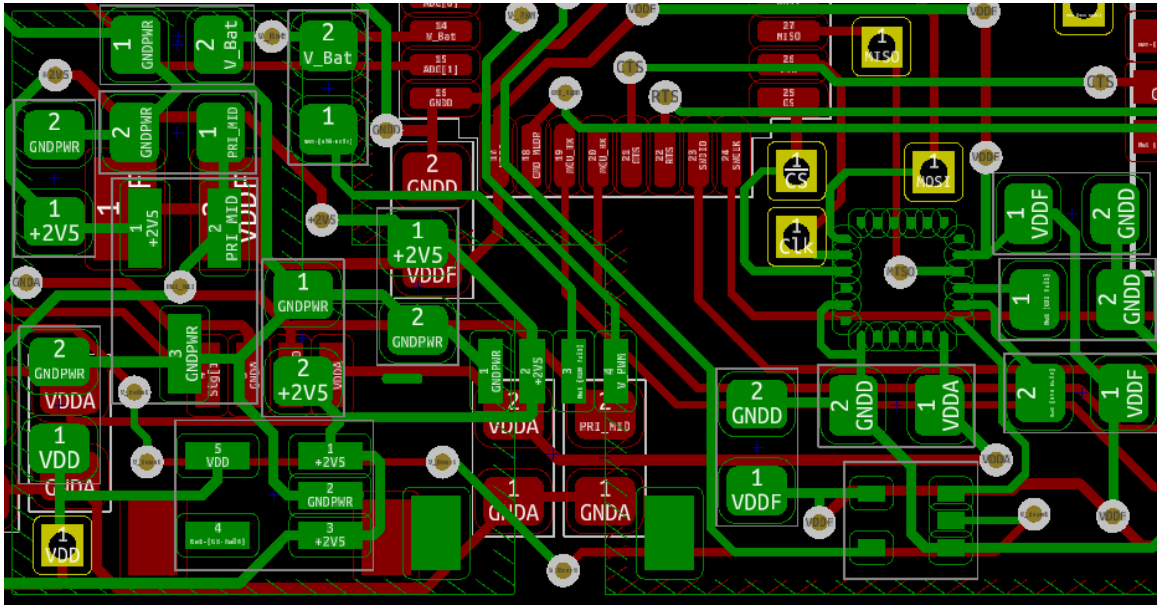
POWER REGULATION AND IMU







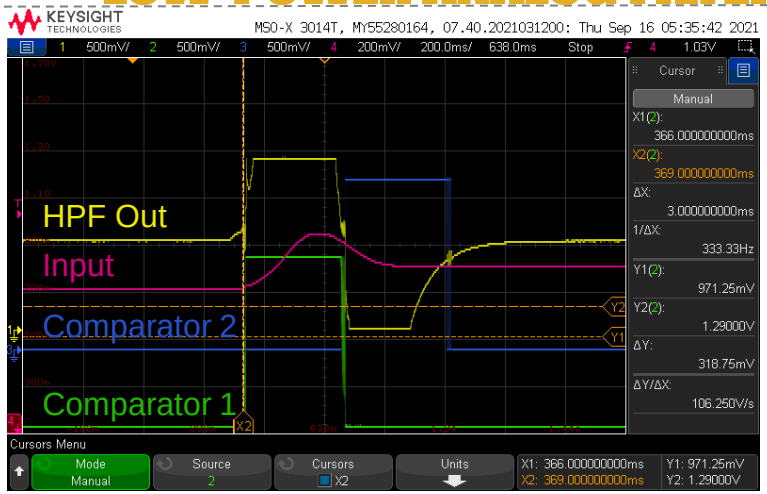


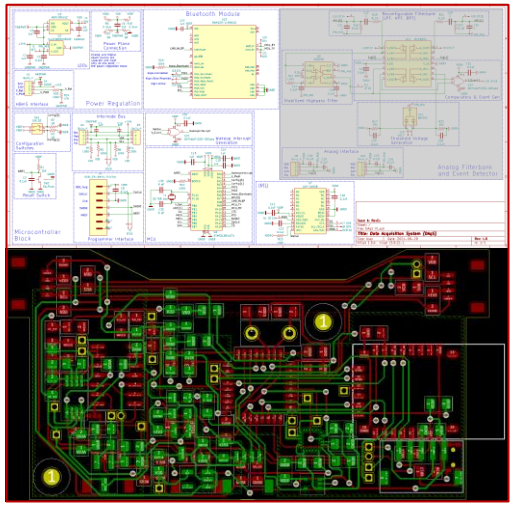


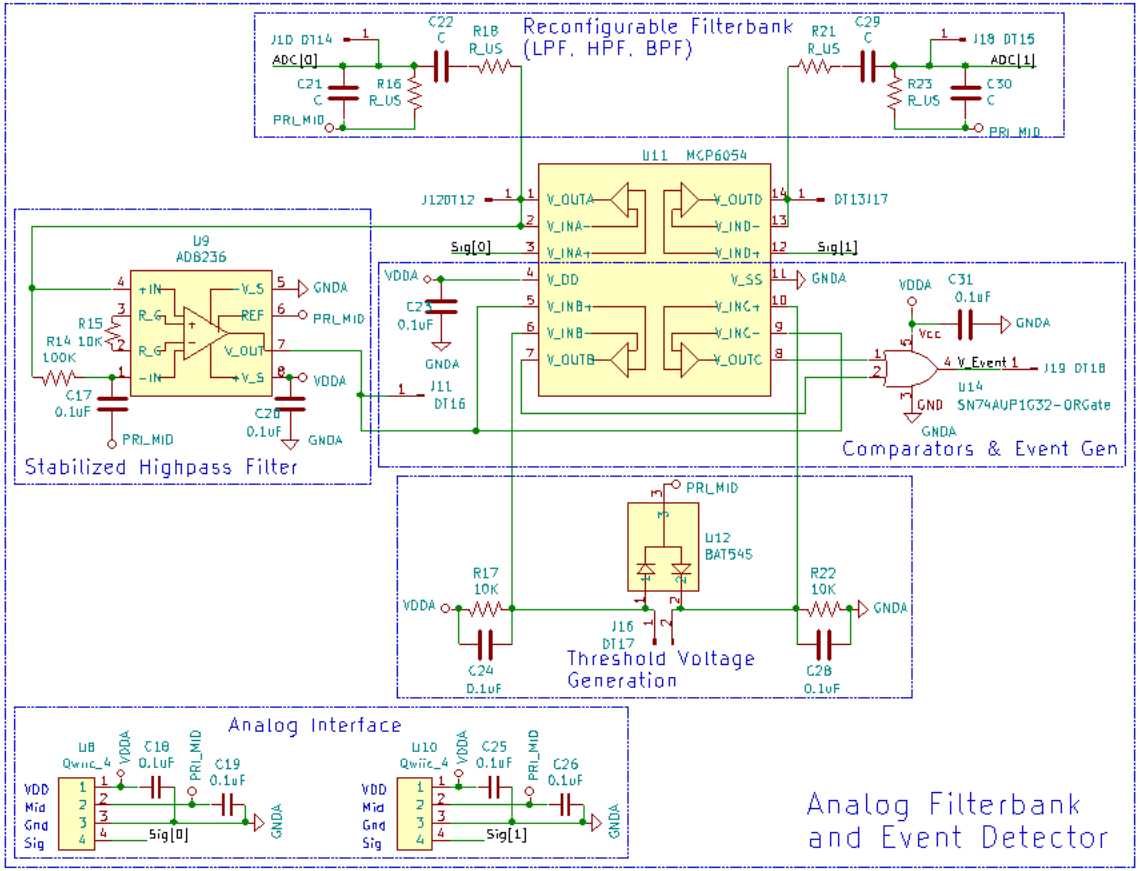
PURDUE
UNIVERSITY

DAoS SCHEMATIC & LAYOUT

LOW-POWER ANALOG FILTERBANK AND EVENT DETECTOR





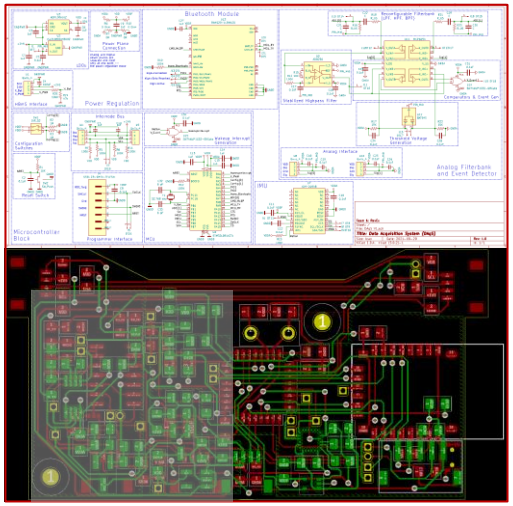


- Highly-reconfigurable topology with tunable sensitivity
- Power Draw: **1.1 mW** (*Including LDO*)
- Latency From Event Onset to Interrupt Output: **3 ms**

PURDUE UNIVERSITY

DAoS SCHEMATIC & LAYOUT

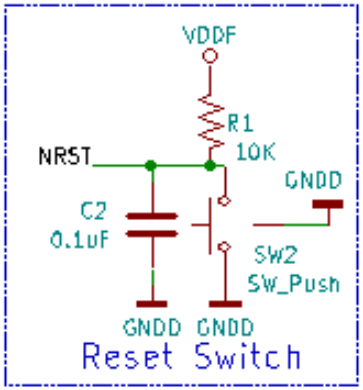
LOW-POWER ANALOG FILTERBANK AND EVENT DETECTOR

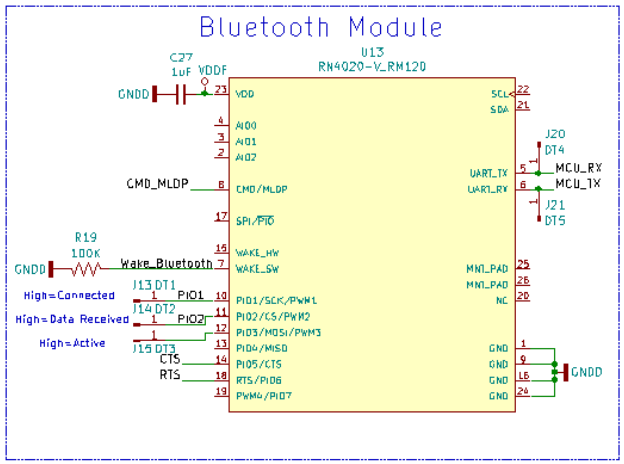


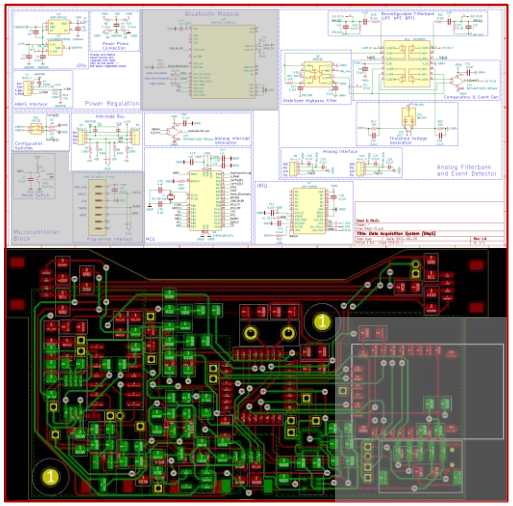
PURDUE
UNIVERSITY

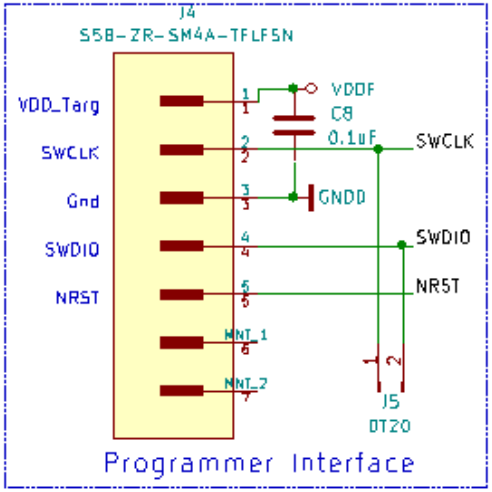
DAoS SCHEMATIC & LAYOUT

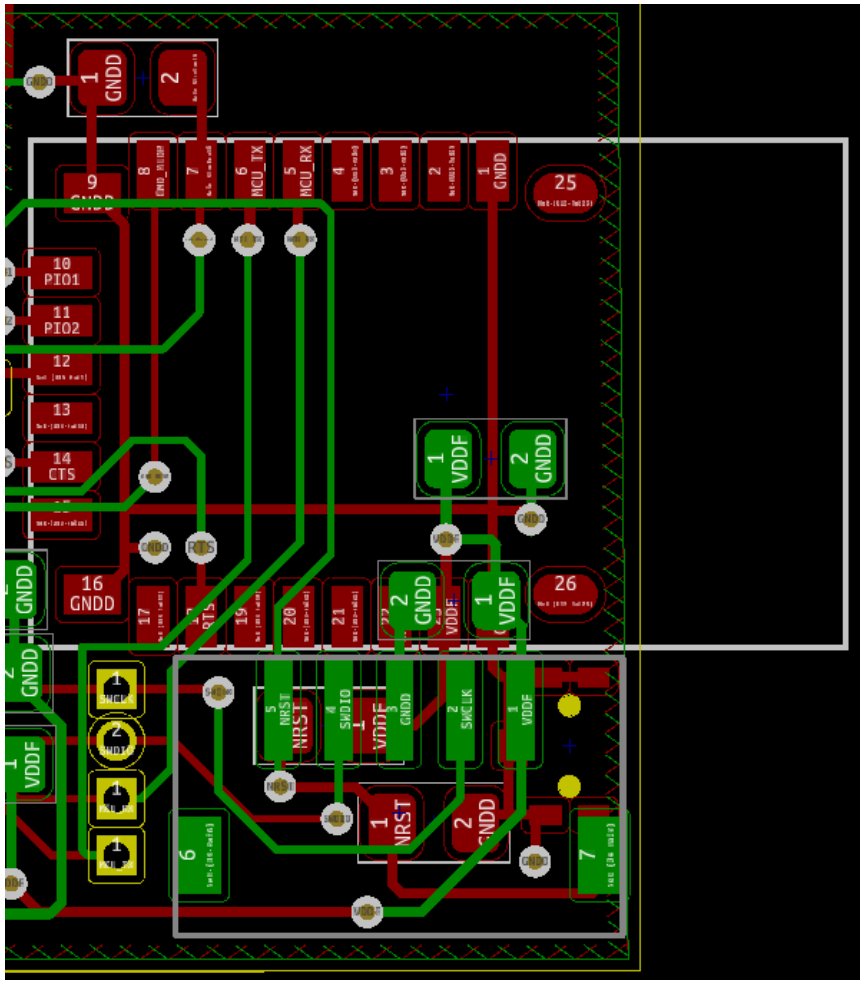
BLUETOOTH MODULE AND SOME MICROCONTROLLER PERIPHERALS







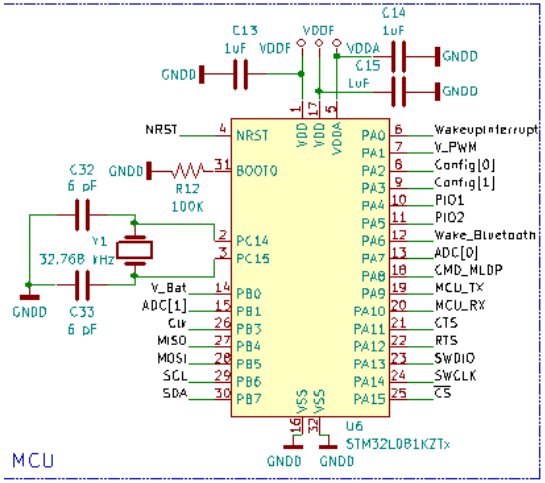


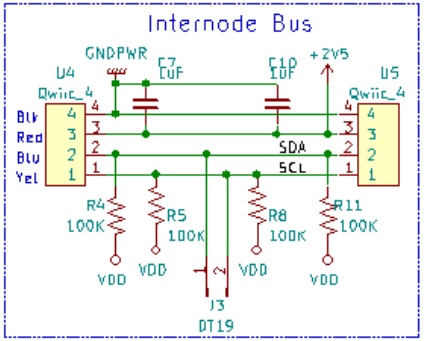


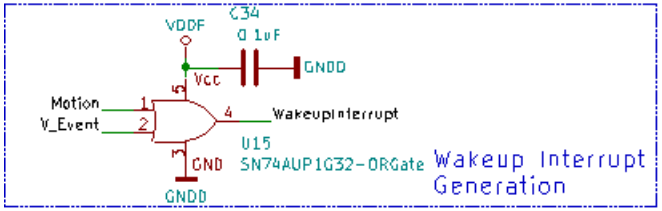
PURDUE UNIVERSITY

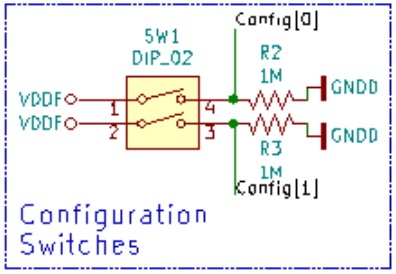
DAoS SCHEMATIC & LAYOUT

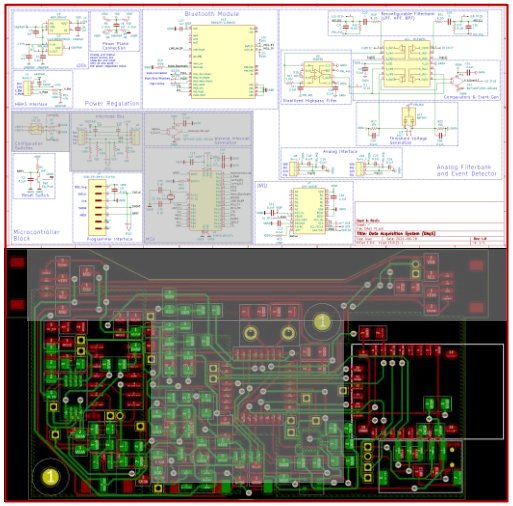
MICROCONTROLLER AND MICROCONTROLLER PERIPHERALS

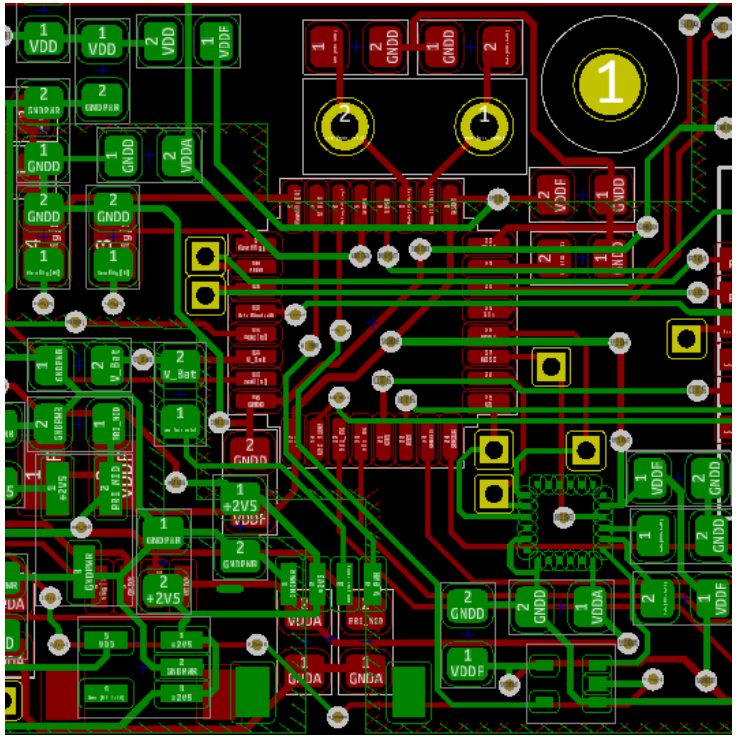


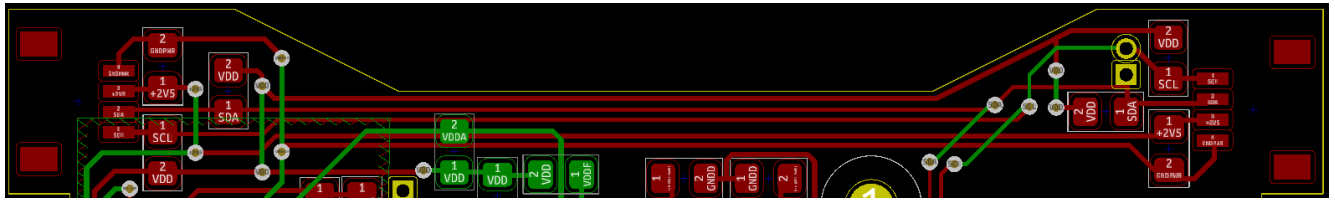












PURDUE UNIVERSITY

PROTOTYPING PROGRESS

HARDWARE (ELECTRICAL)

HBmS Systems:

- Haptic Feedback: Complete
- Energy Harvesting: Complete
- Buck Regulation: Complete
- Battery Charging: In Testing
- Integration: In Testing

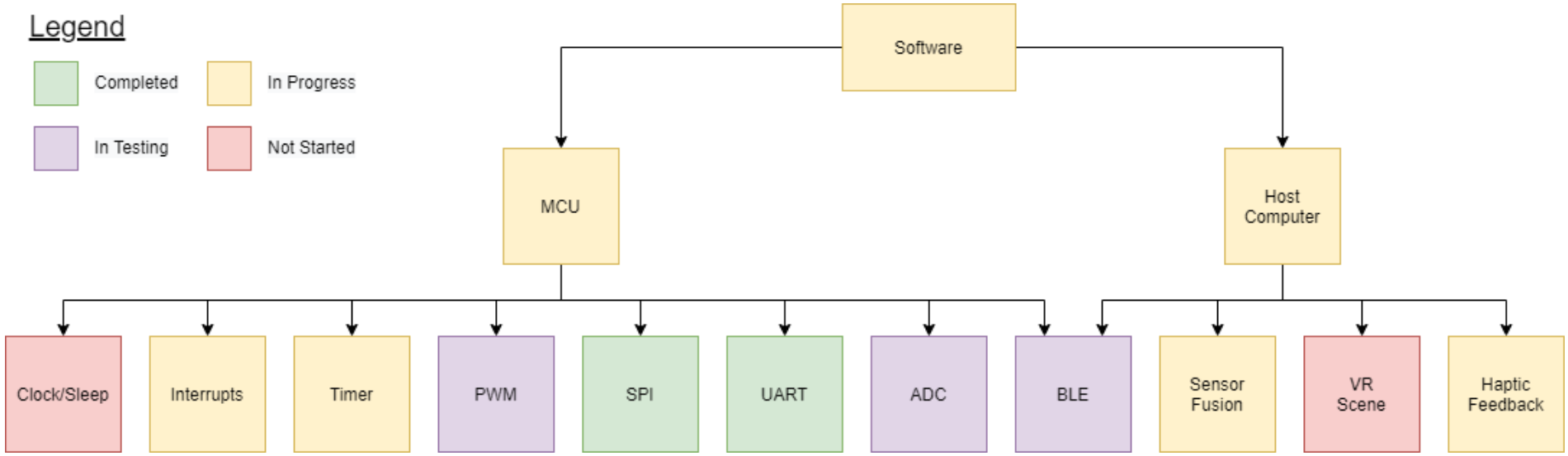
DAqS Systems:

- Analog Event Detector: Complete
- IMU: Complete
- Power Regulation: Complete
- Bluetooth: In Progress
- Potentiometer Breakout: In Progress
- Integration: Not Started
- Microcontroller Peripherals & Internode Bus: Not Started

PURDUE UNIVERSITY

SOFTWARE DEVELOPMENT STATUS

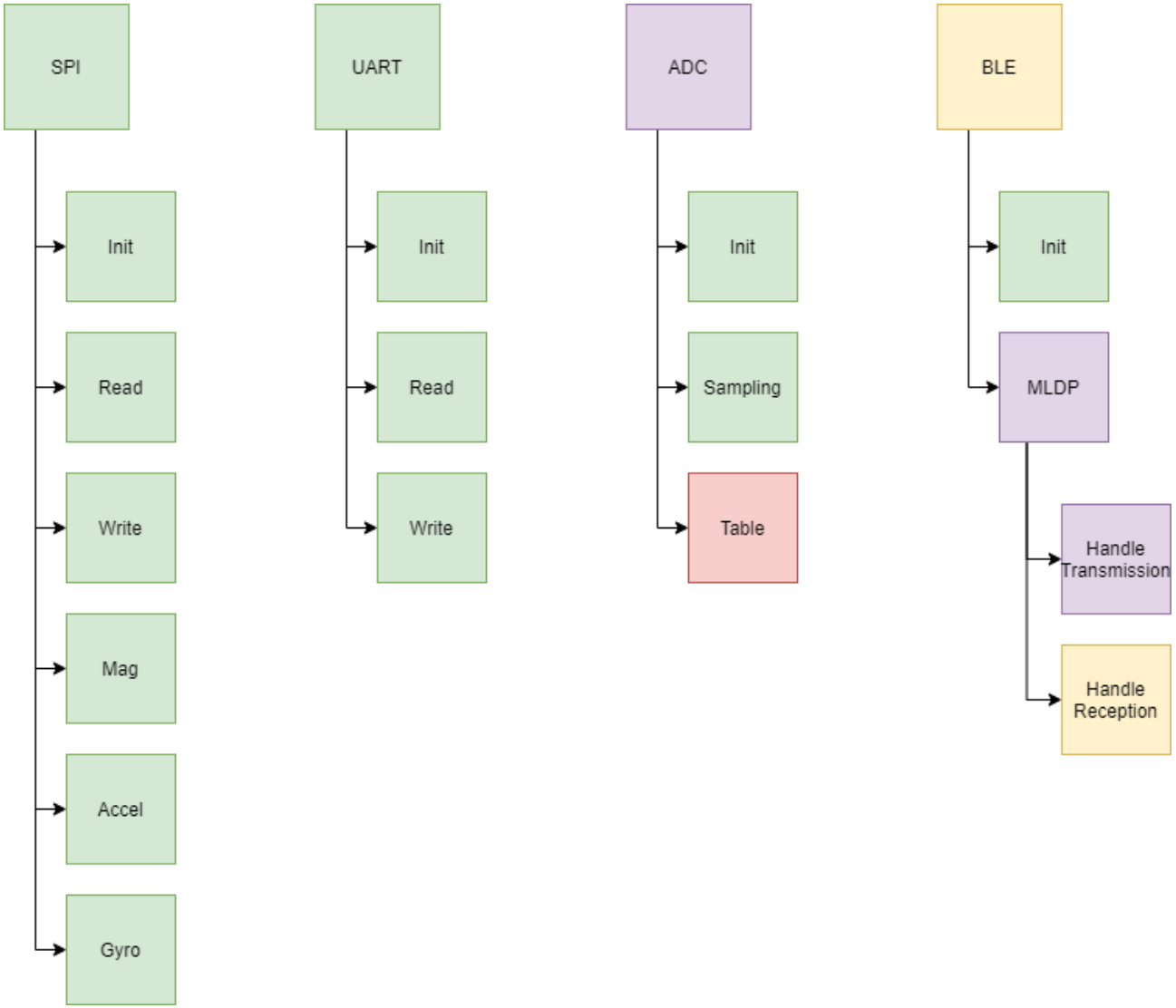
SOFTWARE



PURDUE UNIVERSITY

SOFTWARE DEVELOPMENT STATUS

EMBEDDED SOFTWARE



PURDUE UNIVERSITY

PROTOTYPING PROGRESS

EMBEDDED SOFTWARE

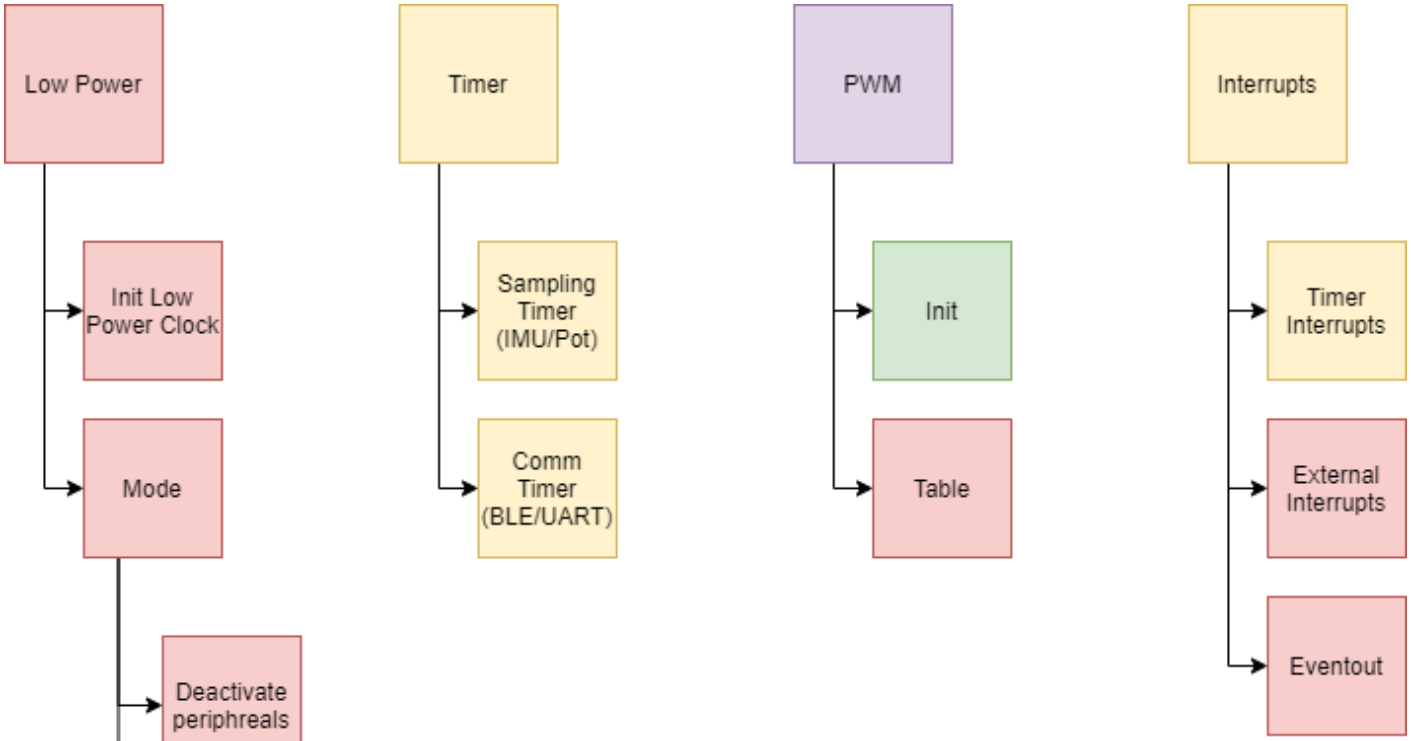
IMU output over SPI
on terminal via UART

```
magnetometer:
x: 49.247963 y: 58.612363 z: 57.471363
gyro:
x: 86.621368 y: 101.641368 z: 83.175768
accelerometer:
x: 5.929640 y: 3.508040 z: 2.323640
magnetometer:
x: 47.995091 y: 57.359491 z: 56.218491
gyro:
x: 85.368500 y: 100.388500 z: 81.922900
accelerometer:
x: 4.676769 y: 2.255169 z: 1.070769
magnetometer:
x: 46.742218 y: 56.106618 z: 54.965618
gyro:
x: 84.950874 y: 99.970874 z: 81.505274
accelerometer:
x: 4.259146 y: 1.837546 z: 0.653146
magnetometer:
x: 46.324593 y: 55.688993 z: 54.547993
gyro:
x: 84.115623 y: 99.135623 z: 80.670023
accelerometer:
x: 3.423898 y: 1.002298 z: -0.182102
magnetometer:
x: 45.489346 y: 54.853746 z: 53.712746
gyro:
x: 82.653938 y: 97.673938 z: 79.208338
```

PURDUE
UNIVERSITY

SOFTWARE DEVELOPMENT STATUS

EMBEDDED SOFTWARE

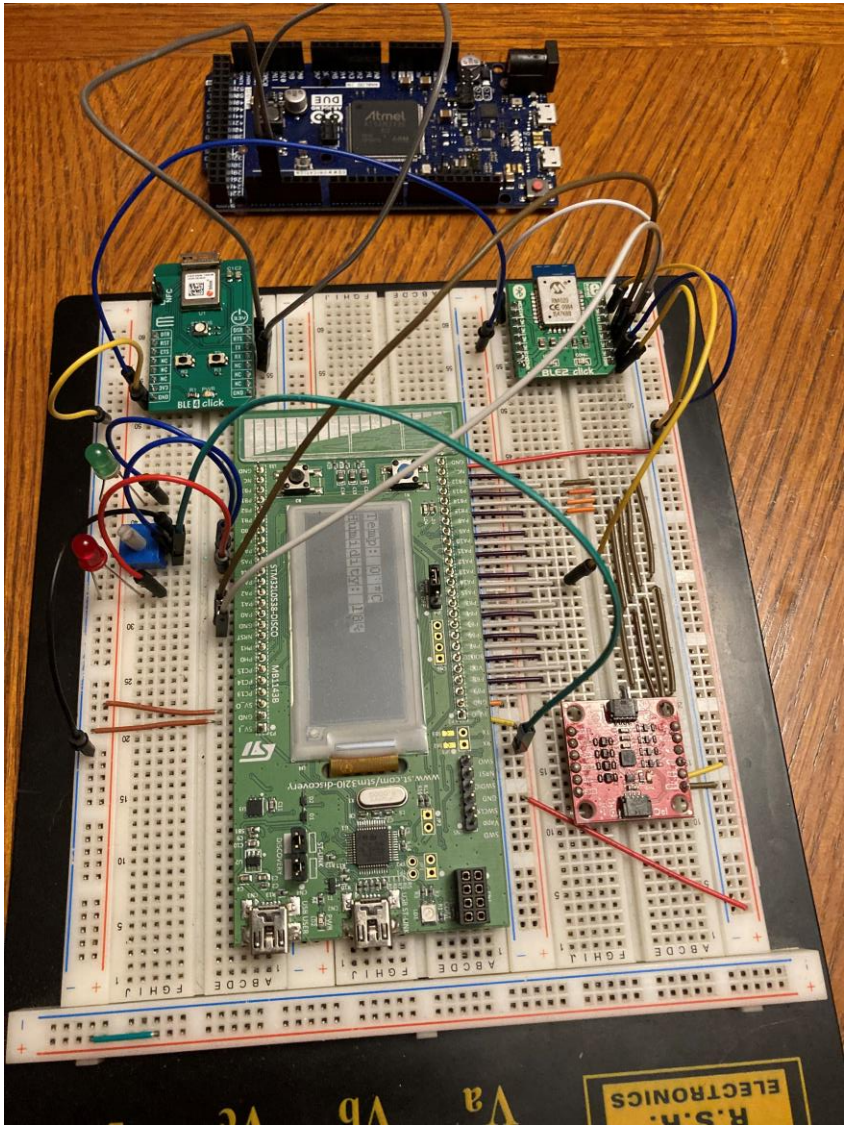


PURDUE UNIVERSITY

PROTOTYPING PROGRESS

EMBEDDED SOFTWARE

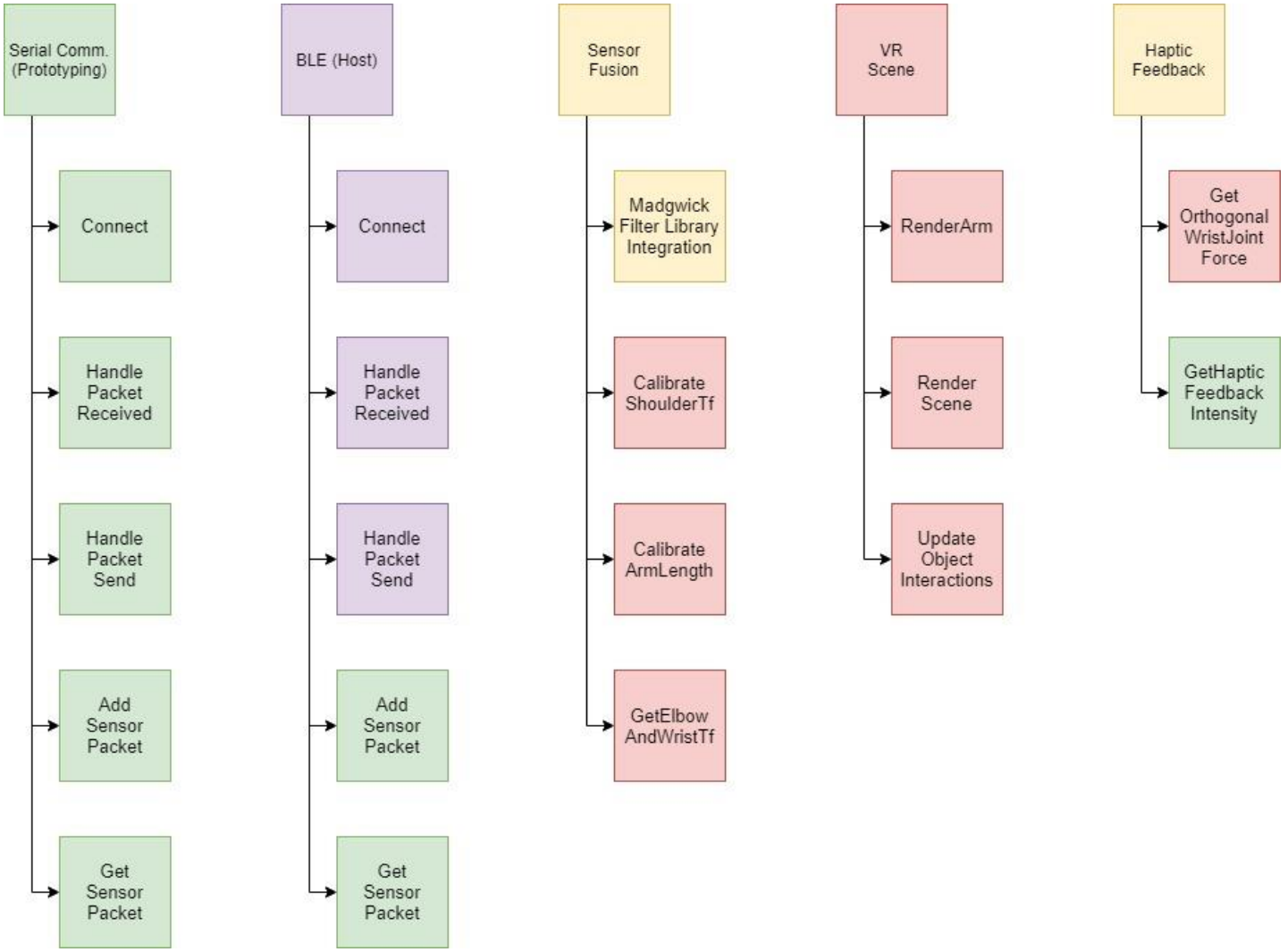
Full breadboard layout for timer/interrupt integration



PURDUE UNIVERSITY

SOFTWARE DEVELOPMENT STATUS

HOST SOFTWARE



PURDUE UNIVERSITY

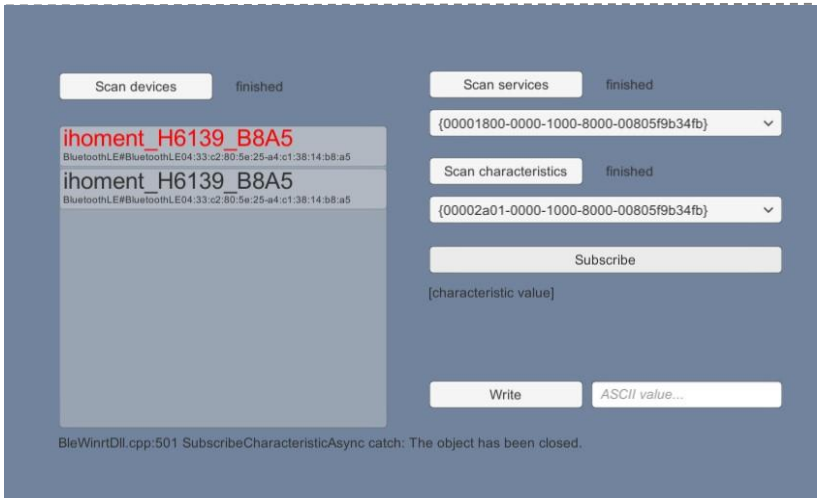
PROTOTYPING PROGRESS

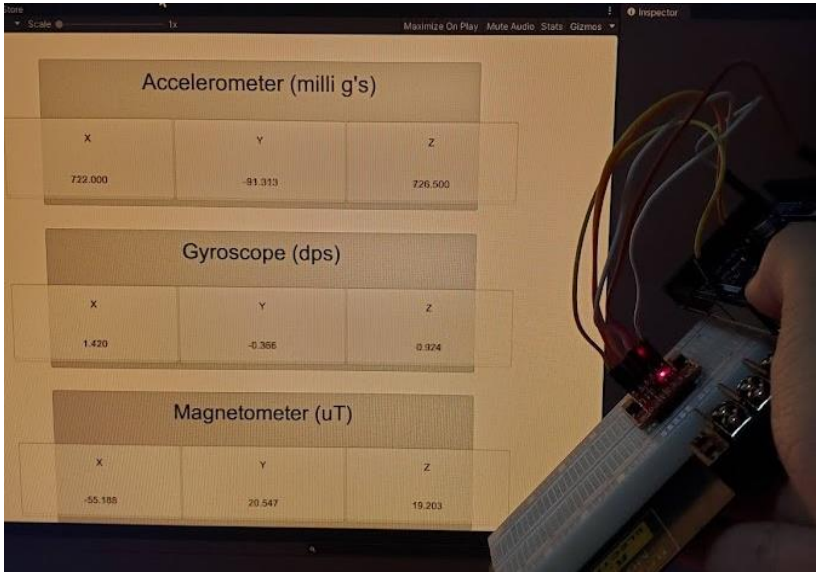
HOST SOFTWARE

- Windows BLE DLL for Unity

- Serial Reader (IMU) and Unity Display

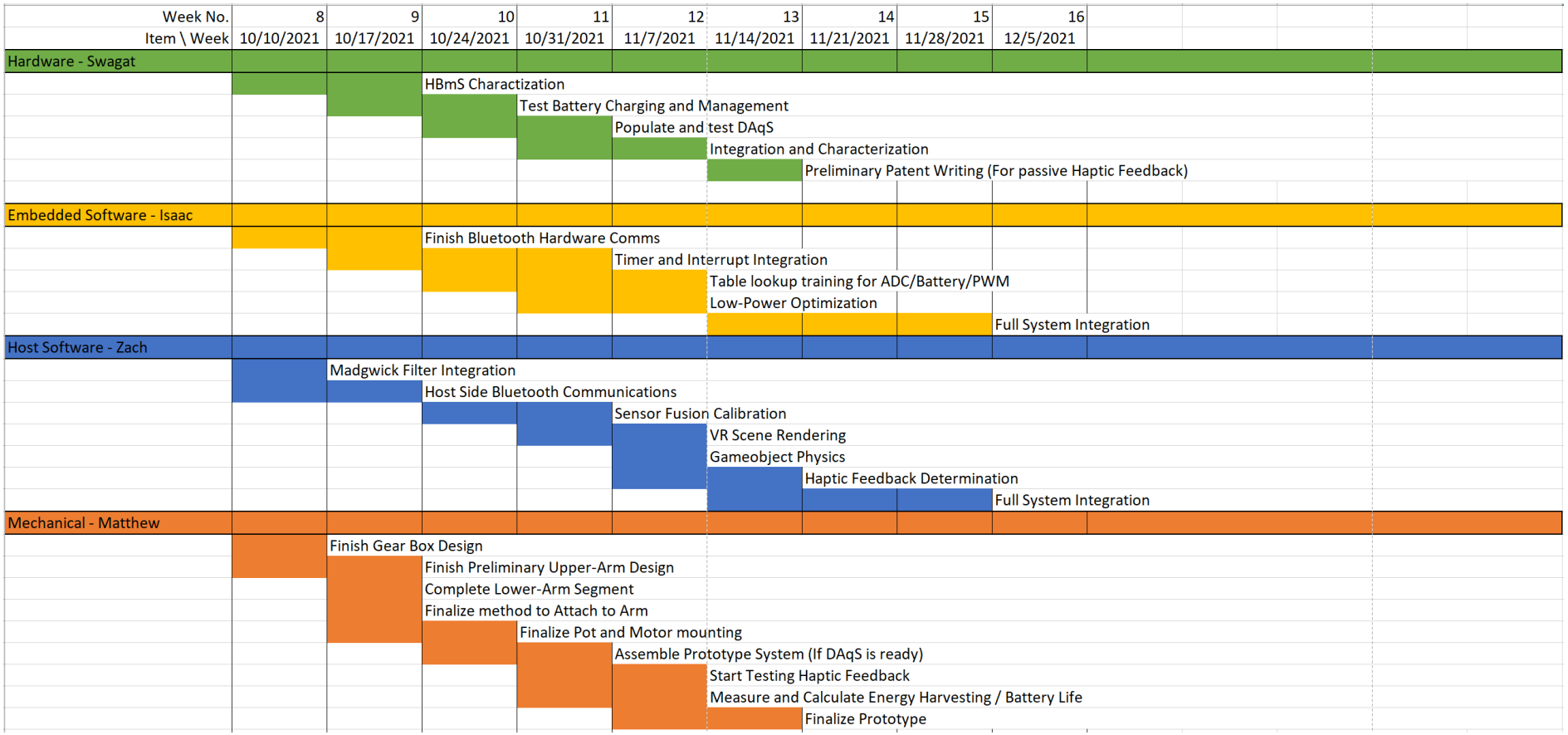
- Madgwick Filter DLL





PURDUE UNIVERSITY

PROJECT TIMELINE



PURDUE UNIVERSITY

Questions?