Review the assignment due date

a14g-final-submission

```
* Team Number:24
* Team Name:IDK
* Team Members:Zhongkun Xue,Yanzhao Wang
* Github Repository URL:https://github.com/ese5160/a14g-final-submission-s25-t24-idk.git
* Description of test hardware: development boards, sensors, actuators, laptop + OS, etc
```

1. Video Presentation

https://drive.google.com/file/d/1_M48jvQlfONuINd9gaB8aoC9x6r87ObH/view?usp=sharing

2. Project Summary

Device Description: The Tennis Swing Trajectory Tracker is a compact IoT device that attaches to a tennis racket to record, display, and analyze swing motion in real-time. It provides immediate visual feedback, stores swing data, and enables players to pause and review performance using a built-in LCD.

Device Functionality: The system consists of an ICM-20948 9-axis sensor (accelerometer, gyroscope, magnetometer), a SAMW25 microcontroller, an ST7735R LCD, an SD card module, and a switch button, all powered by a Li-Ion battery and mounted on a custom-designed compact PCB. The LCD shows real-time trajectory, the button pauses recording and displays recent swings, and Wi-Fi enables remote data transfer.

Challenges：One of the biggest challenges we encountered was managing memory allocation efficiently within FreeRTOS. Specifically, we struggled with minimizing each task's `task size` to fit within the limited available memory. Additionally, designing an algorithm to convert raw 9DOF IMU data into an accurate 3D swing model proved complex. These challenges pushed us to deeply understand task scheduling, memory optimization, and coordinate transformation under real-time constraints.

Prototype Learnings：

Through building and testing this prototype, we gained valuable experience in hardware design and embedded system integration. We learned how to design more debug-friendly PCBs by incorporating jumpers and breakouts, which made testing and troubleshooting significantly easier. We also became much more comfortable using FreeRTOS, particularly in managing concurrent tasks and ensuring time-sensitive operations are handled correctly.

If we rebuilt this device , we would redesign the PCB layout to better fit the physical structure of the tennis racket and select a more reliable and precise IMU sensor. This would improve both mechanical integration and sensor accuracy, ultimately enhancing the overall performance of the device.

Next Steps & Takeaways：

Although the device is already functional and well-integrated, one current limitation is the inability to transmit IMU data in real time to external applications like Unity, due to restricted memory. To complete the project and enable full real-time motion replication, we would need to increase available RAM or use more efficient task handling. This would allow us to stream data continuously for live 3D swing visualization.

From ESE5160, we learned the importance of RTOS in embedded development, particularly how to schedule and isolate tasks in real time. We also developed a strong understanding of bootloader structure, firmware update mechanisms, and the complete development cycle of an Internet-connected embedded system—from PCB layout to cloud communication.

Project Links：

Node-Red

http://48.217.65.123:1880/ui

PCB：

https://upenn-eselabs.365.altium.com/designs/54467BE2-7B2A-4019-87E0-7CC7A92E9B56

3. Hardware & Software Requirements

Hardware Requirements Specification (HRS)

Requirement ID	Requirement Description	Performance Metric	Achievement
HRS 01	The system shall use the ICM-20948 sensorfor 9-axis motion tracking.	Sensor data sampled at up to 1.1 kHz.	YES
HRS 02	The system shall display metrics in real-time using the ST7735R LCD.	Display refresh rate ≥ 30 FPS.	NO
HRS 03	The system shall use the SAMW25 microcontroller to manage data processing and Wi-Fi communication.	Data transmission latency ≤ 100 ms.	NO
HRS 04	The hardware shall be powered by a single-cell Li-Ion battery(3.7V nominal voltage).	Battery life ≥ 4 hours.	YES
HRS 05	All components shall be integrated into a custom PCB for compact and portable design.	PCB dimensions ≤ 500x500 mm.	NO
HRS 06	The system shall include Wi-Fi functionality for data transmission via the SAMW25.	Wi-Fi range ≥ 10 meters indoors.	YES
HRS 07	The hardware shall include an SD card slot for data storage and retrieval.	Data write speed ≥ 3 MB/s.	NO

Requirement ID	Requirement Description	Performance Metric	Achievement
HRS 08	The system shall include a switch button to pause sensor recording and activate review mode on the LCD.	Button response time ≤ 100 ms.	YES
HRS 09	The PCB shall include appropriate voltage regulators to provide 3.3V and 5V as needed for all components.	Voltage output variation ≤ ±0.1V.	YES
HRS 10	The hardware shall withstand typical tennis swings without detachment or damage.	Withstand forces up to 30g acceleration.	YES

For HRS 04, 05, 06, 08 the performance can be directly observed by eyes or measured easily. HRS 01: We do it by checking the number of data read in 1 second directly in a csv file. HRS 02: This requirement we found it unnecessary as we only want to refresh numerical data on it so we don't have specific requirement on that. HRS 03: Set log timestamps before sending and after receiving data. Calculate the latency and confirm it is ≤ 100 ms. HRS 08: Record the time between a button press and the corresponding LCD update using timestamps. HRS 09: Use a multimeter and oscilloscope to measure the outputs on your PCB HRS 10: Check the IMU Reading directly after swinging the racket and see if the largest acceleration measured can hold 30g. (But of course we don't need this kind of speed in the end.)

Software Requirements Specification (SRS)

Requirement ID	Functionality Description	Performance Metric	Achievement
SRS 01	The system shall collect and process motion data from the ICM-20948 sensor.	Data processing within 100 ms.	YES
SRS 02	The software shall display real-time metrics and trajectory simulations on the ST7735R LCD.	Metrics updated at 30 FPS.	NO

Requirement ID	Functionality Description	Performance Metric	Achievement
SRS 03	The system shall pause data recording and display the last recorded data when the switch button is pressed.	Pause functionality response ≤ 100 ms.	YES
SRS 04	The software shall store swing data on an SD card for later retrieval.	Write speed ≥ 5 MB/s.	NO
SRS 05	The system shall transmit processed data wirelessly using the SAMW25 microcontroller.	Wi-Fi latency ≤ 100 ms.	NO
SRS 06	The software shall retrieve and display previously stored swing data from the SD card.	Data retrieval within 200 ms.	YO
SRS 07	The software shall indicate system status via the LCD.	LCD updates within 1 second.	YES
SRS 08	The software shall simulate the simple swing trajectory on LCD after click the button.	LCD update the trajectory within 3 second	NO
SRS 09	The computer software shall simulate the 3D version of swing trajectory.	Simulation within 1 mins	YES

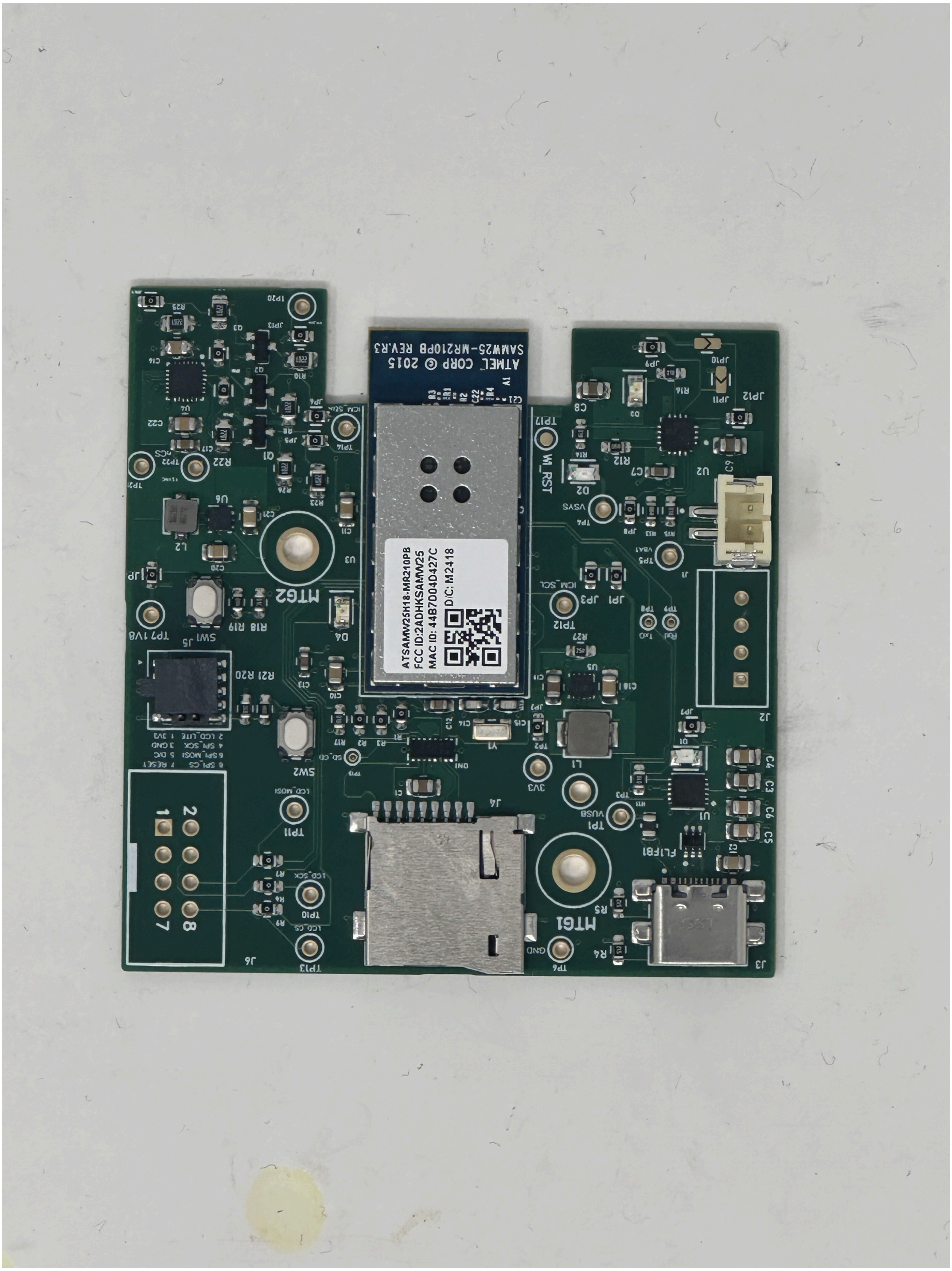
SRS 02, 03, 04, 07, 09 can be directly visually observed and do not need specific method. SRS 01: Using timestamps to get the duration. SRS 05; We found it is hard to archieve as it need http knowledge and our stack size is also not large enough for the csv file so we give up this part and use the SD card to transmit the data. SRS 06: Same as 01 and this is the part done by our pc. SRS 08: We show the trajectory using Unity instead since it is hard to show the orientation of the racket on the LCD while Unity ca build the 3d Model of racket.

4. Project Photos & Screenshots

*** Required photos and screenshots include:

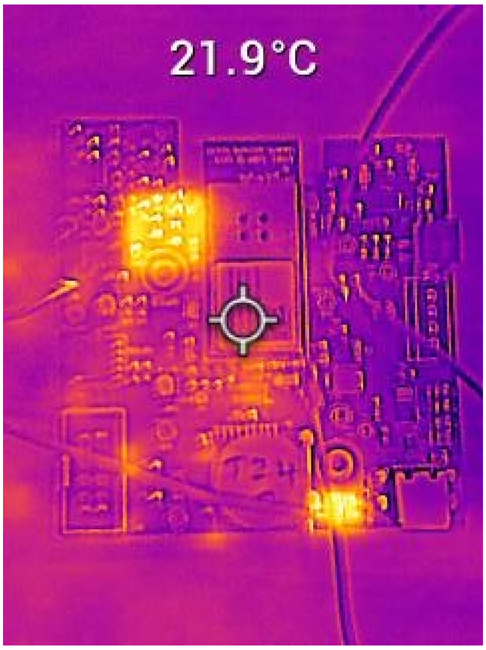
- Your final project, including any casework or interfacing elements that make up the full project (3D prints, screens, buttons, etc)

- The standalone PCBA, top



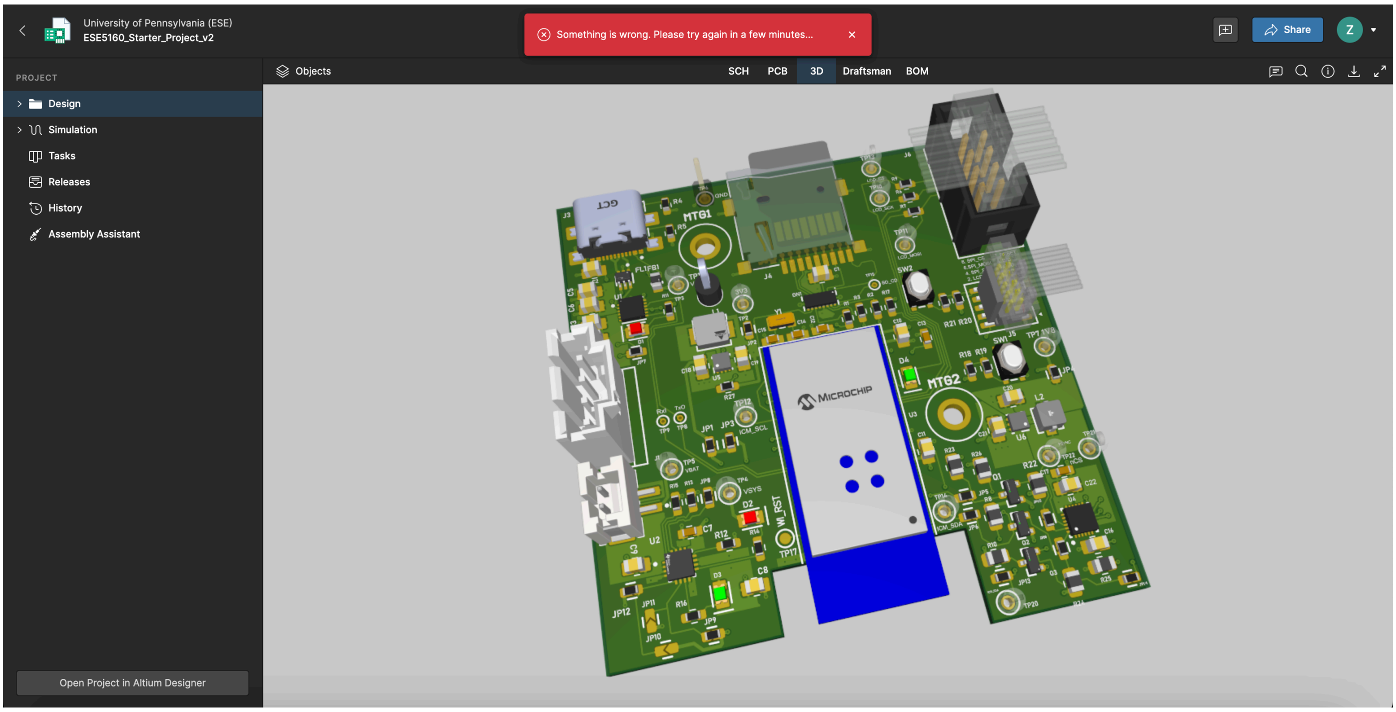
- The standalone PCBA, bottom

- Thermal camera images while the board is running under load (you may use your Board Bringup Thermal image here!)

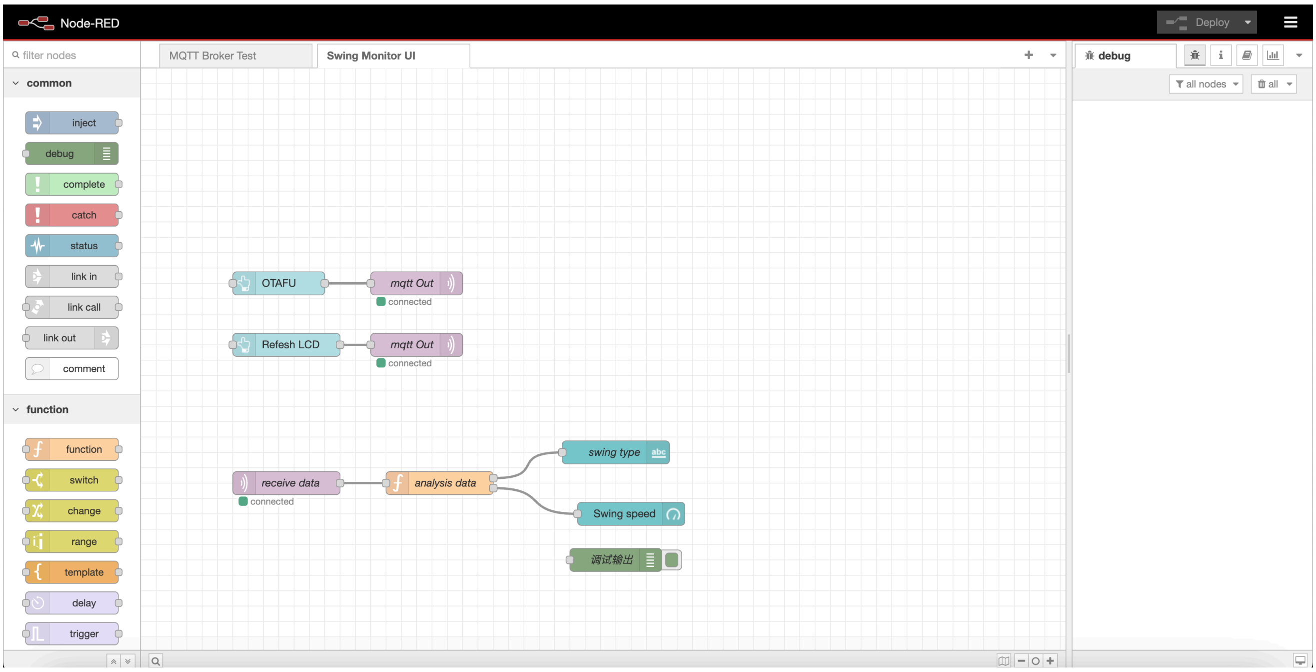


- The Altium Board design in 2D view (screenshot)

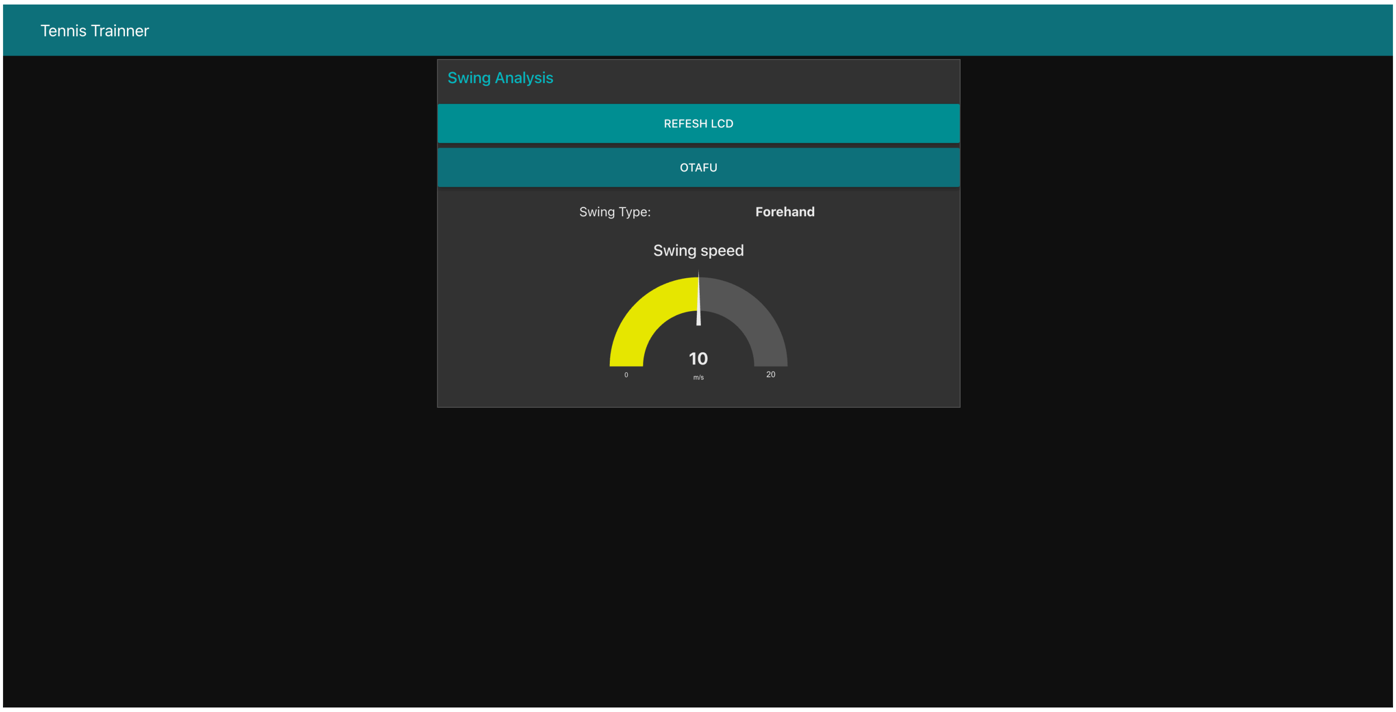
- The Altium Board design in 3D view (screenshot)



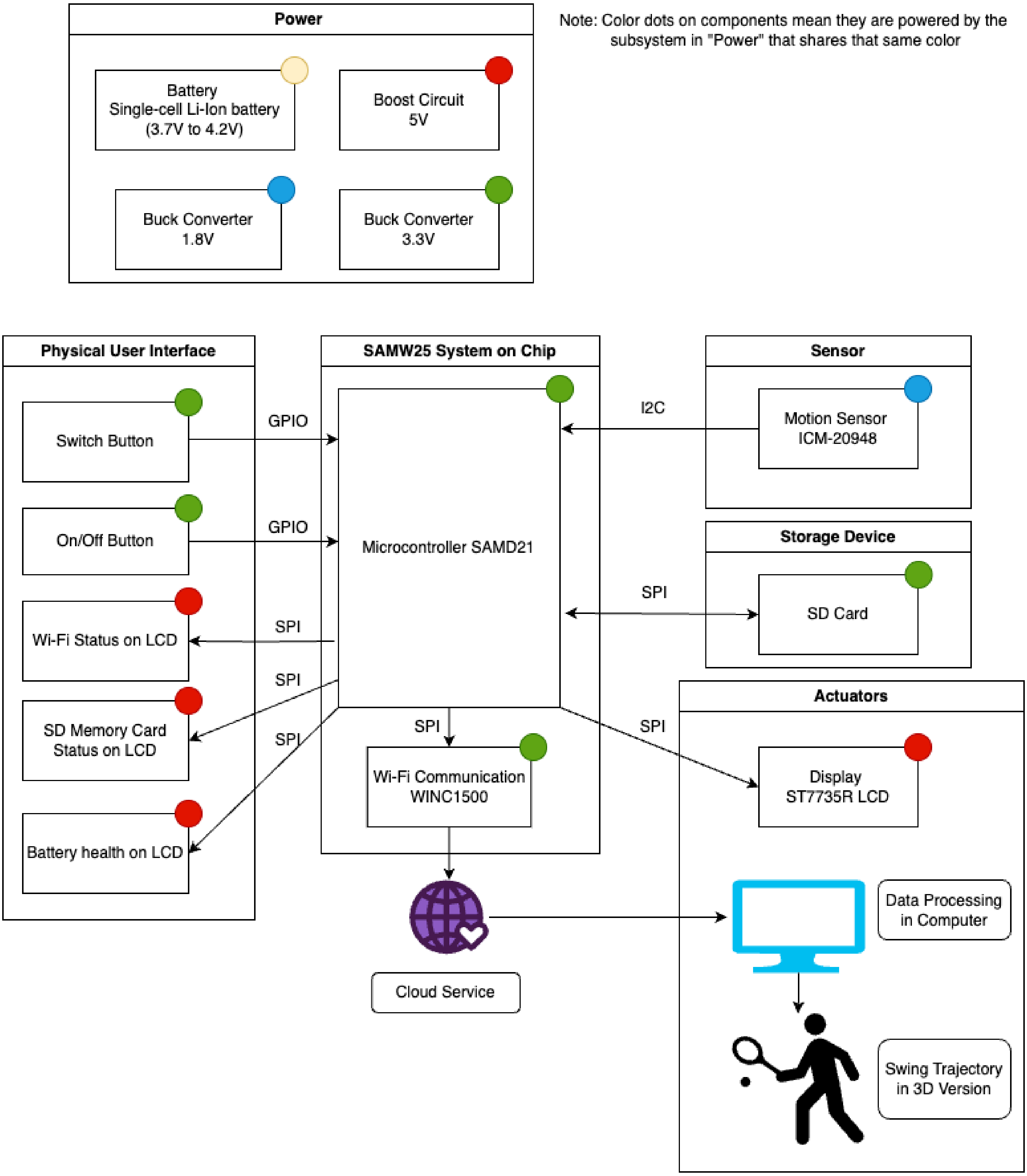
- Node-RED dashboard (screenshot)



- Node-RED backend (screenshot)



- Block diagram of your system (You may need to update this to reflect changes throughout the semester.)



**

Codebase

- A link to your final embedded C firmware codebases: https://github.com/ese5160/final-project-t24-idk.git
- A link to your Node-RED dashboard code: http://48.217.65.123:1880
- Links to any other software required for the functionality of your device