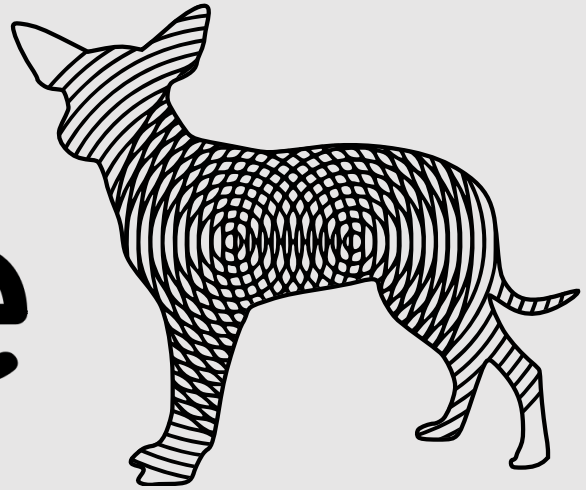
LoRaware



Optimized Wireless Patient Monitoring

Master of Science in Electrical Engineering Capstone Project

Babatope Erinfolami, Antwane Green, David Rodriguez, Jorge Quiroga

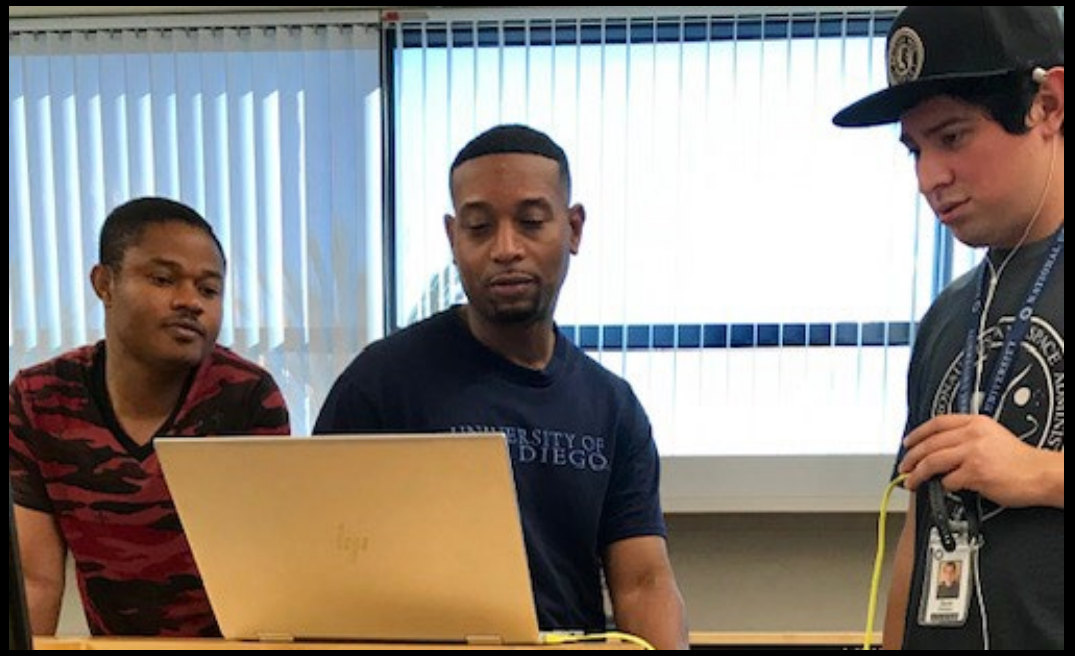
Dr. Mohammad Amin, National University

Introduction and Content

- Project Team
- Research
- Project Objectives
  - System Requirements
  - System Design
  - System Components
- Development
  - Spectrum
  - Component Integration & Assembly
  - System Management
  - Tools (HW/SW)
- Testing and Analysis
- Project Management
- Future Capabilities & Research
- Closing Points & Demo

Project Team

- Babatope (Sam) Erinfolami
  - Graduate of the Federal Polytechnic Ado-Ekiti, Nigeria, Higher National Diploma (BSEE equivalent)
- Antwane Green
  - Graduate of the University of San Diego (USD) with a BSEE
- David Rodriguez
  - Graduate of New Mexico State University with a BS in Engineering Physics and Mechanical Engineering
- Jorge Quiroga
  - Graduate of CSU San Jose, BSME; Naval Postgraduate School with a MS Operations Research; University of Phoenix , MBA



Research - Project Selection Background

- Many Individuals are admitted to hospitals reporting minor to medium ailments or symptoms that are later discovered to be indicators of more severe underlying problems.

- At any point within their stay, these patients initially deemed “low-risk”, will be left unattended and waiting
  - To meet with a Doctor, Nurse, or Specialist
  - For Test Results to be Processed and Evaluated

- 75% of preventable hospital deaths outside of the ICU, occur while unmonitored (AHA Database, 2013)

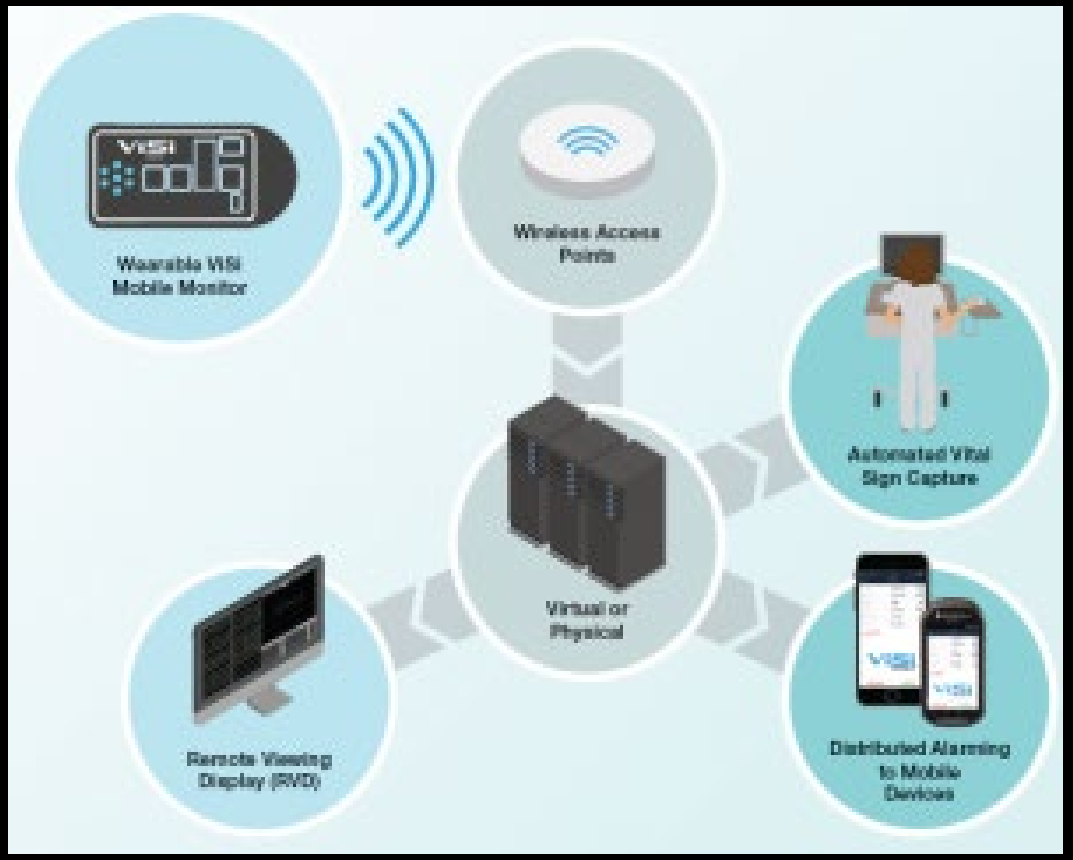
Source: https://www.soterawireless.com/wp-content/uploads/2016/03/14_SOT_005_ViSi_Brochure_8.5x11_Digital.pdf

Research – Other Related Applications

- According to the World Health Organization (WHO)
  - In 2015
    - over 17.7 million people died from cardiovascular diseases
    - 31% of the global deaths
  - Raised emphasis on health awareness, prevention of various vascular diseases and fitness
  - Increase in use of wearable medical devices and fitness devices, results in increased demand for these types of devices
  - The global Heart rate monitors market is expected to grow at a Compound Annual Growth Rate of 13.50% (According to the Market Research Future MRFR press release) during forecast period 2017-2023

Research - Commercially Available Products

- Wireless Device Power Consumption Benchmark Based on Sotera Wireless ViSi Patient Monitoring System: 14 – 16 hours



Source: https://www.soterawireless.com/resources/

Research - Wireless Patient Monitoring

- Commercially Available Solutions show Room for Optimization
- Problems stem from using Wi-Fi on Wireless Wearable Sensor Devices
  - Bulky devices due to Large Batteries
  - Relatively Short Battery Life
  - Built on Expensive Proprietary Tools, Utilities, and Applications
  - More Devices on Existing Networks Compete for Available Bandwidth
- The Use-Case of monitoring low-risk Patients (not admitted to ICU) suggests a greater importance on Reliability and Security, rather than High Speed and High Data Transfer Rates.
- End-Users of these products
  - Hospitals and clinics
  - Sports medicine centers
  - Medical Professionals & Researchers

Project Objectives

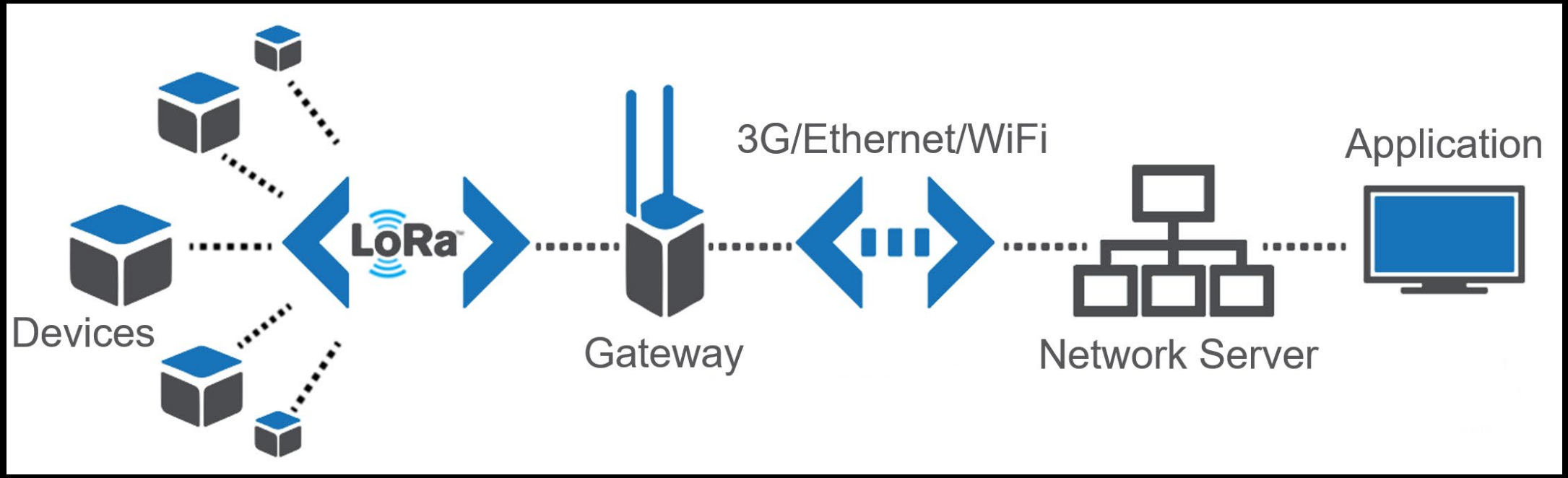
- Design, prototype, test, and manufacture an industry-competing wireless patient monitoring system including
  - 4 Custom Wearable Sensor Node Devices
  - Database Hosted on Webserver
  - Data Visualization Platform Hosted on Webserver
- Use low cost components, free & open source software
- Use Commercially Available Wireless Patient Monitoring System as Benchmark in terms of
  - Power Consumption / Battery Life (14 – 16 Hours)
  - Size & Formfactor
  - Cost of System Deployment
- Test Wireless Device Performance, Compare Estimated Results with Measured Results

Objectives - System Requirements

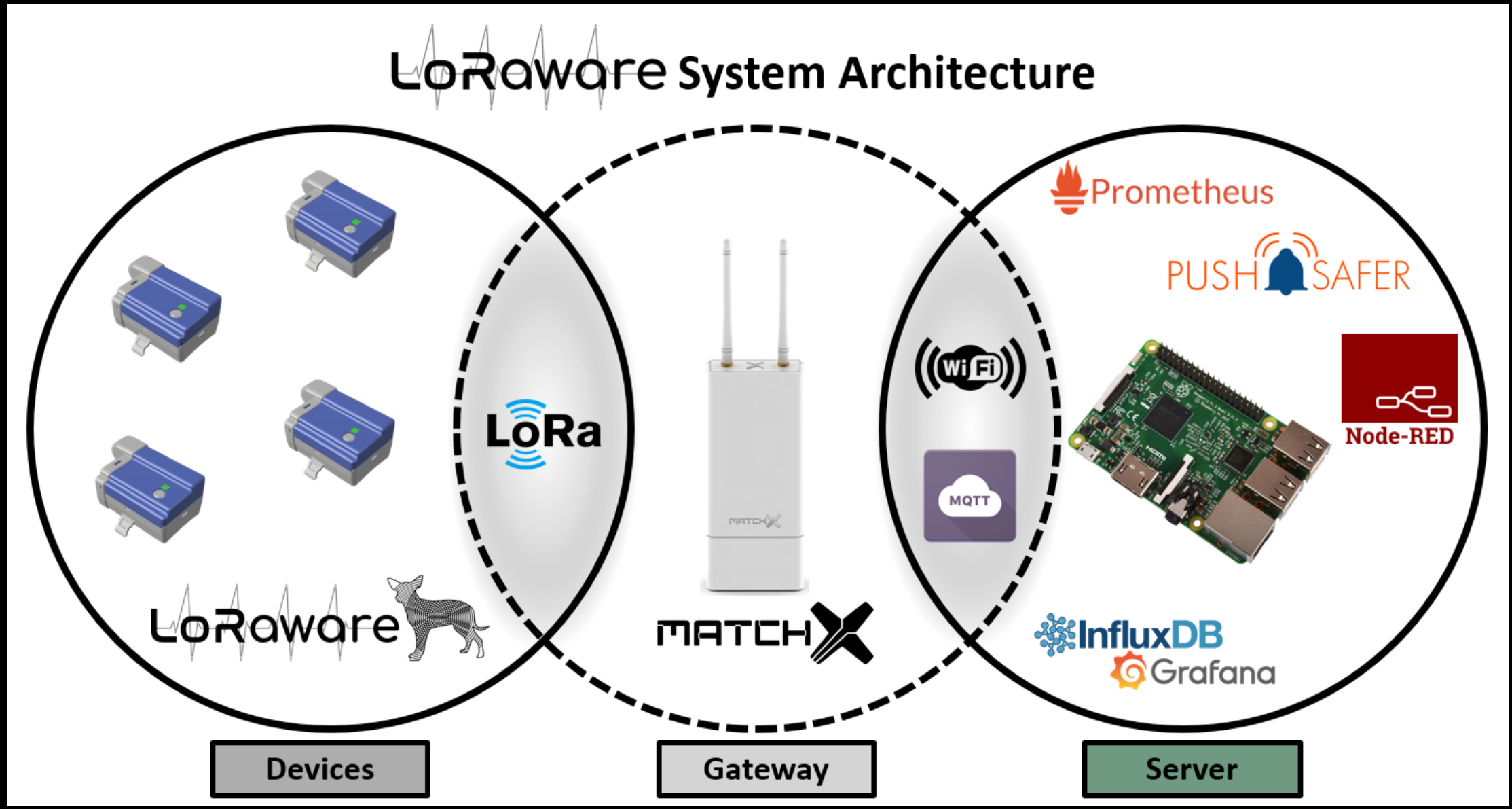
- Reliable Storage, Monitoring, and Data Visualization Access
- No Reliance on pre-existing Wi-Fi Infrastructure
- No Interference with pre-existing Wi-Fi Infrastructure
- Secure Transfer of Patient Biometric Data
- Battery Life exceeding 16-hours

Objectives – Employ LoRaWAN Architecture

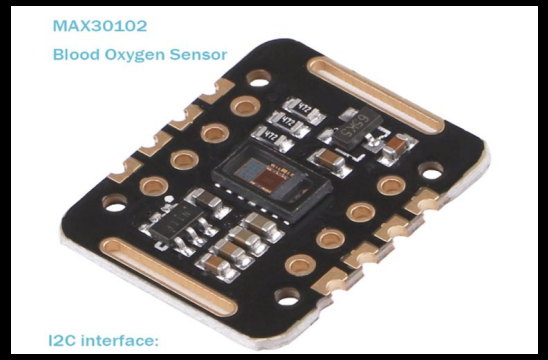
- Standard Network Topology

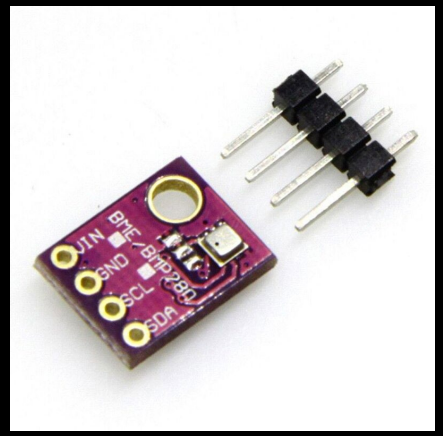


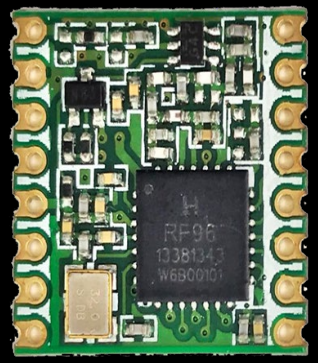
Objectives - System Layout



Objective – Low Cost Device Components







Control:

- ESP32 Microcontroller

Transducers:

- MAX30102 Heart Rate Sensor and Blood Oximetry Sensor
- BME280 Temperature and Humidity Sensor

RF:

- RFM95W RF Module
- LoRa 915 MHz Antenna

Power:

- 2000 mAh Lithium (Li) Ion Polymer Battery
- TP4056 Li-ion Charge Protection Integrated Circuit (IC)

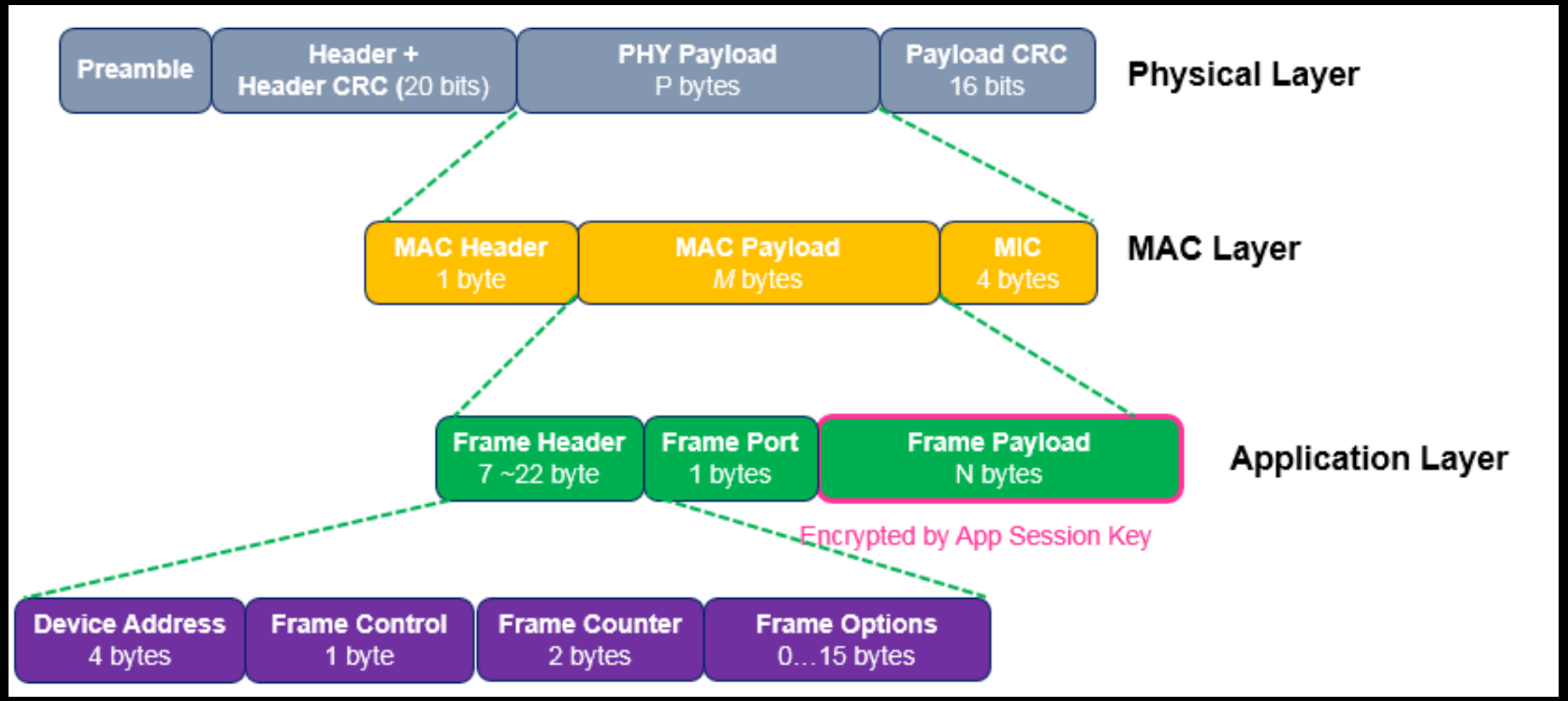
Integration and Structure:

- Printed Circuit Board (PCB)
- Case

Objectives – Network Security

- LoRa Physical Layer Encryption
  - Network Session Key – 128-Bit AES Encrypted Frame (Header + Payload), used to sign the message for Network Server to verify ID of sender
  - Application Session Key – 128-Bit AES Encrypted Payload Value in Frame, only decrypted by the Application running in Gateway
- Server-Side Encryption

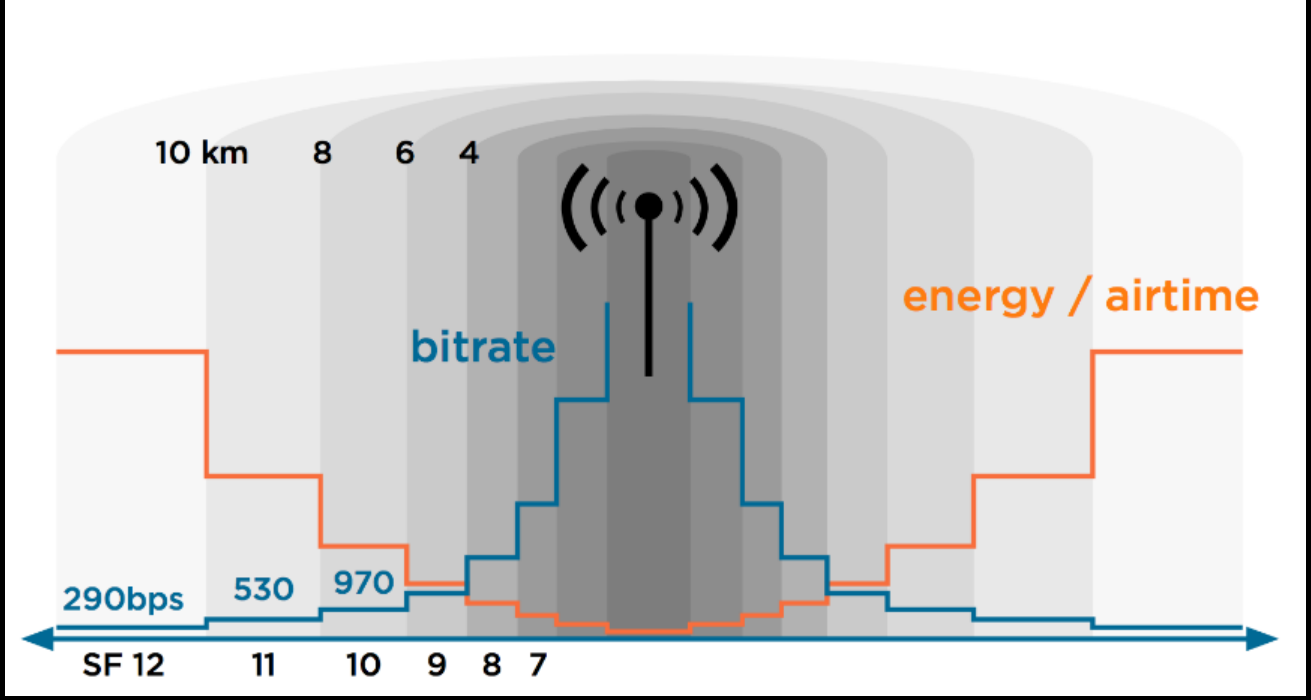
  TLS Encryption via SSL Certificate

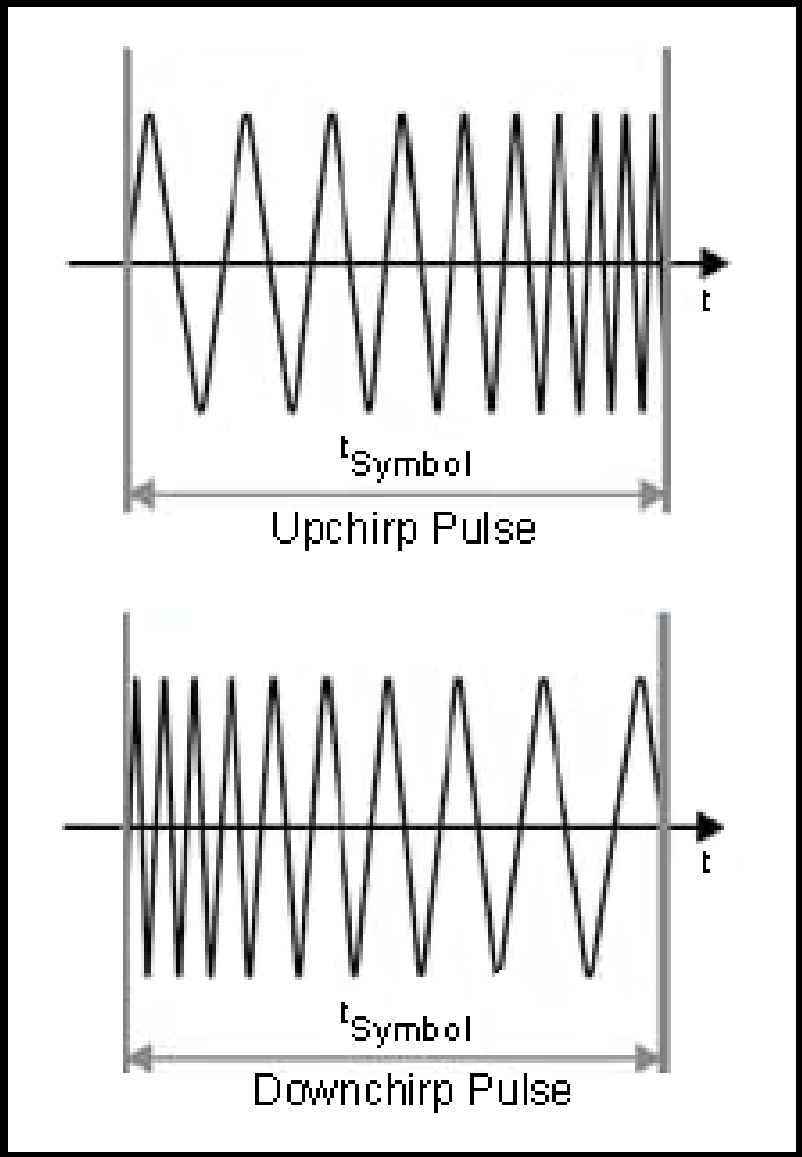


LoRaWAN Packet Structure

Development - LoRa “Physical Layer”

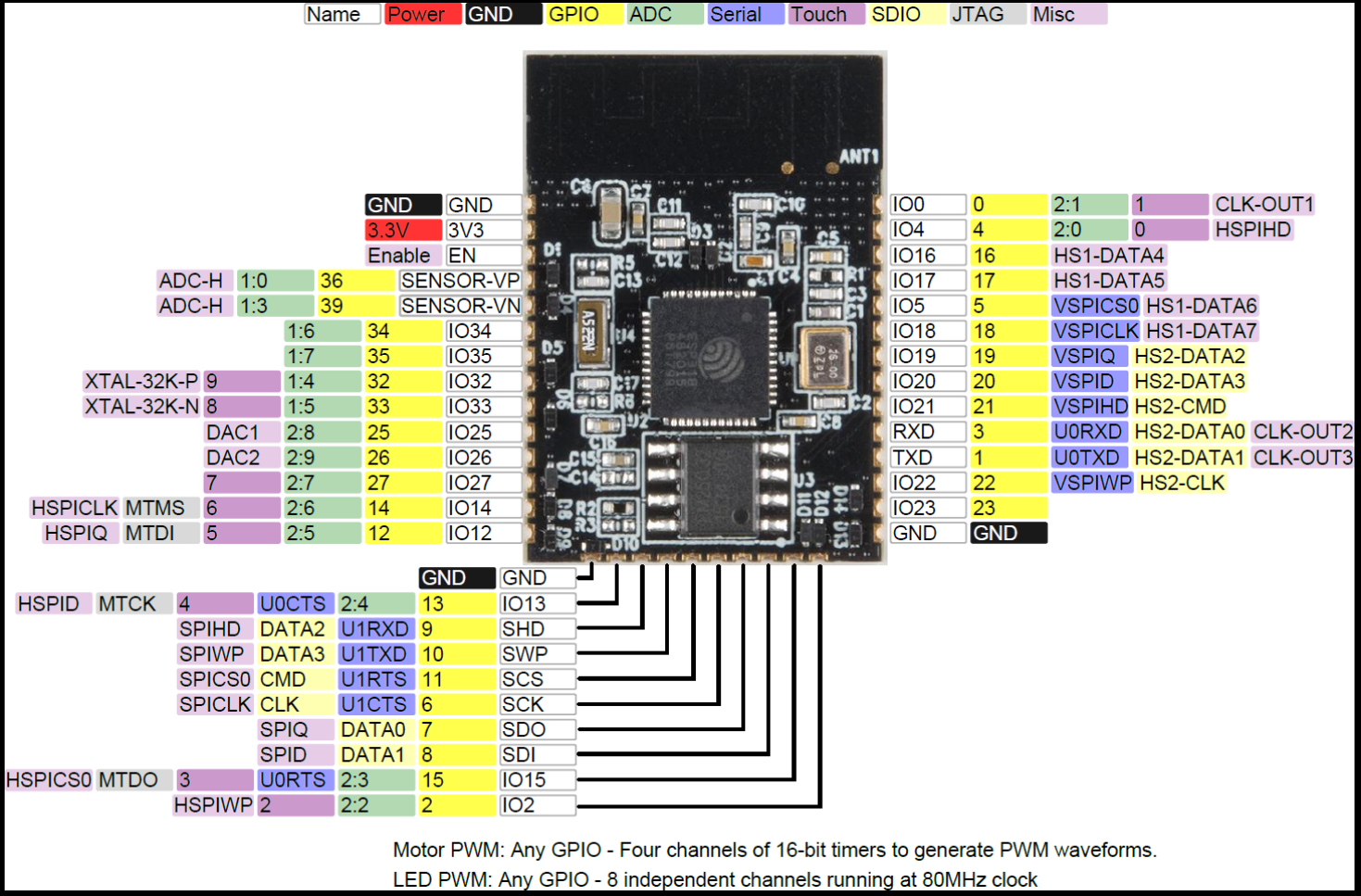
- Uses a modified Chirp Spread Spectrum Modulation Technique borrowed from IEEE 802.15
- Spread Spectrum AKA Spreading Factor – used to improve range and data rate by adjusting transmission power to distribute data across wider bandwidth of the spectrum
- Forward Error Correction



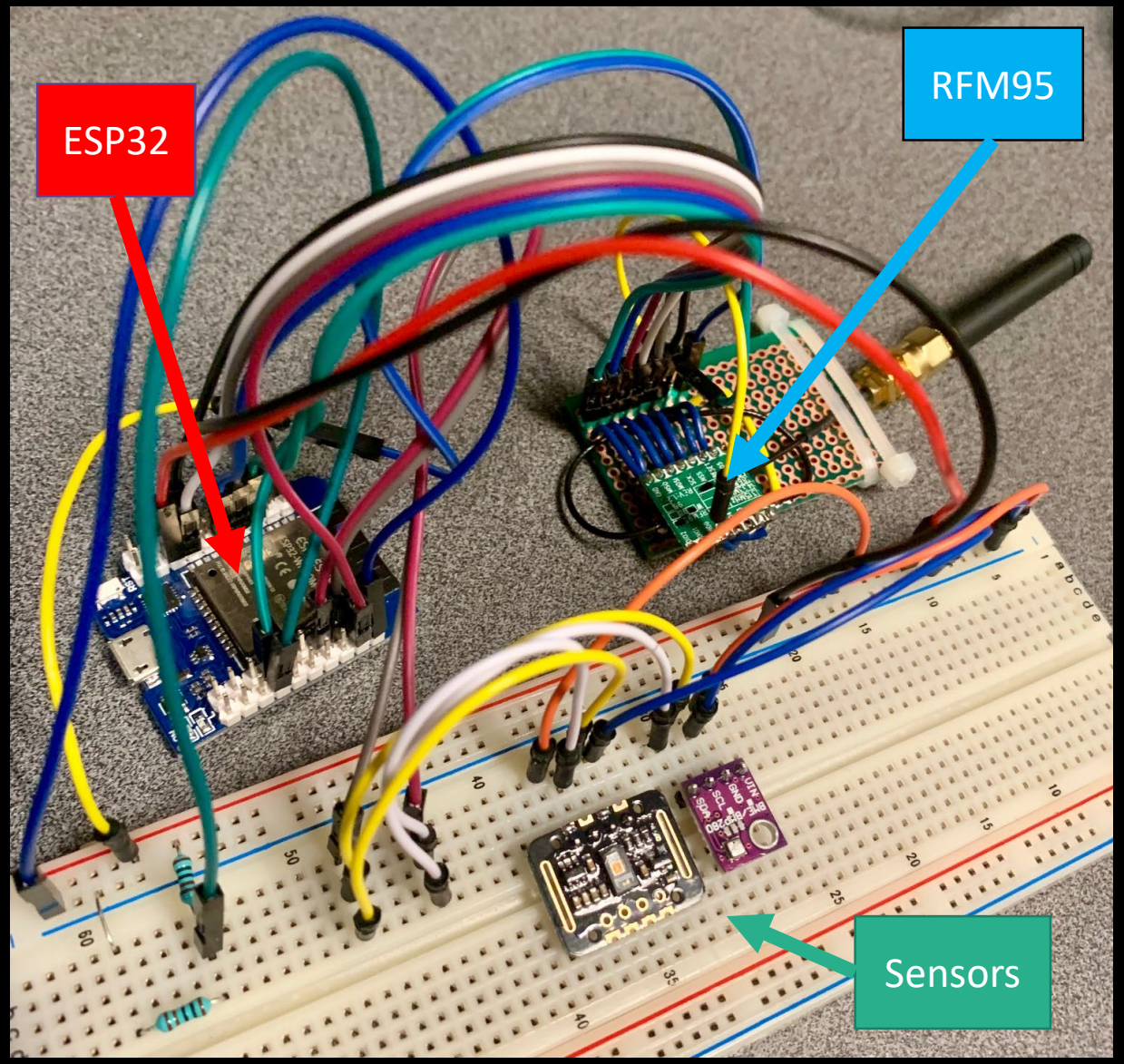


Development - Why use the ESP32 as main processor in LoRaware wearable devices?

- Function
  - Low Cost
  - Low Power
  - Wi-Fi
  - Bluetooth 3.0 & 4.0

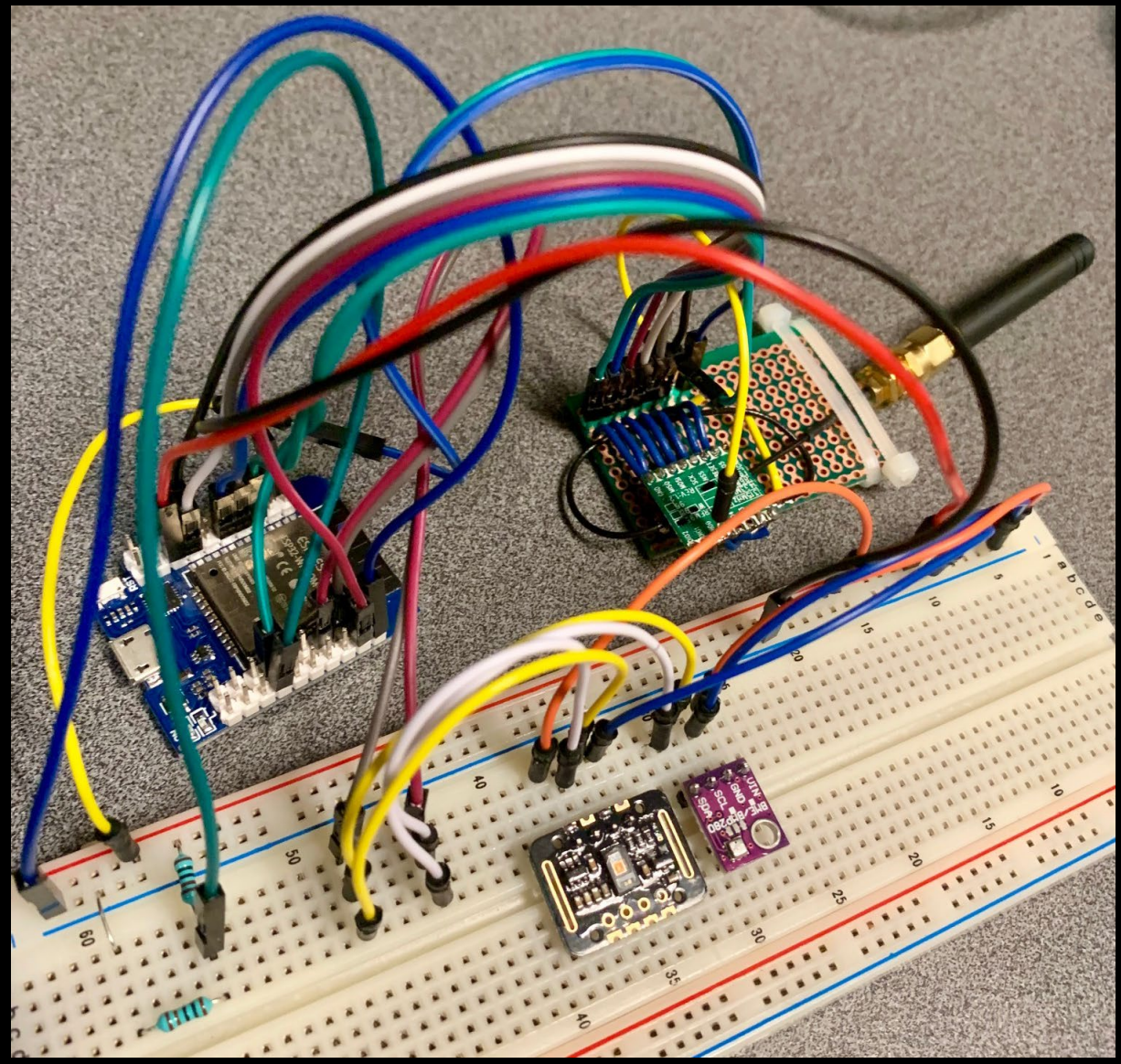


Development – Device Proof of Concept



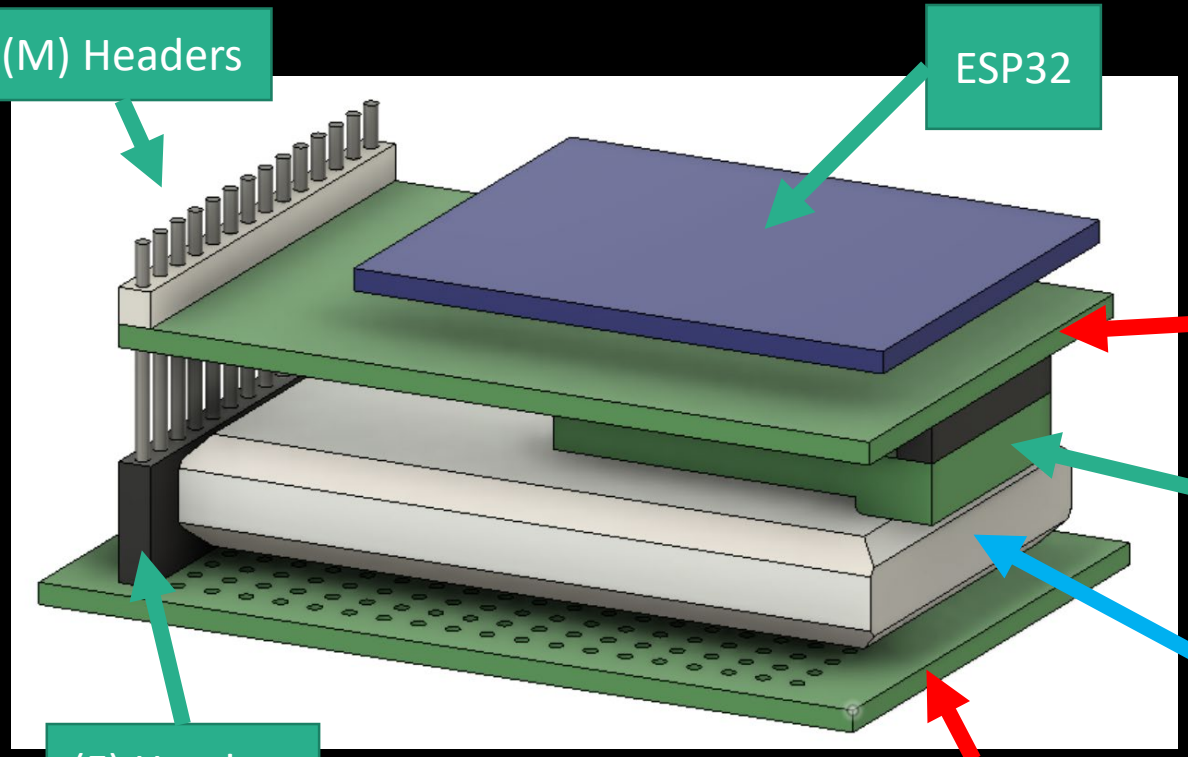
Development – Device Proof of Concept Results

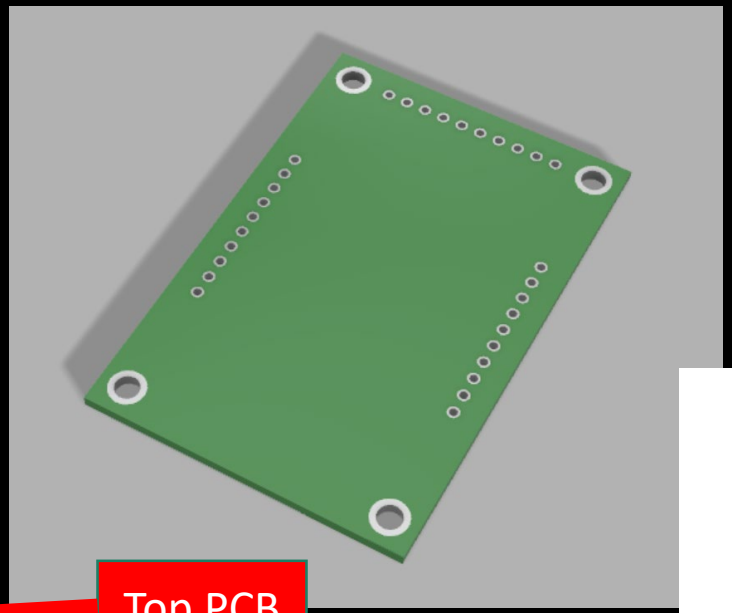
- Sensor Measurements facilitated by processor
- Packet transmitted in 915 MHz ISM Band with Unencrypted Payload
- LoRa Point-to-Point Configuration with single Receiver
- Did not use LoRaWAN

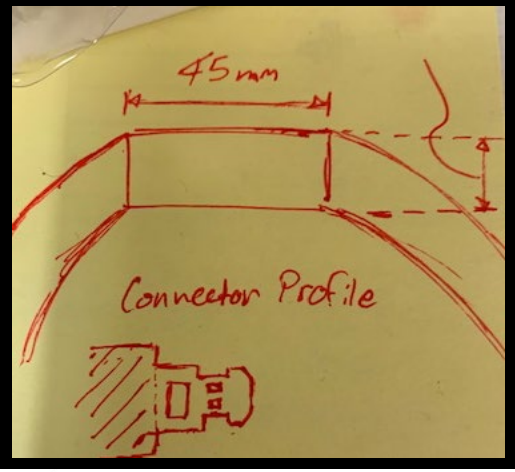


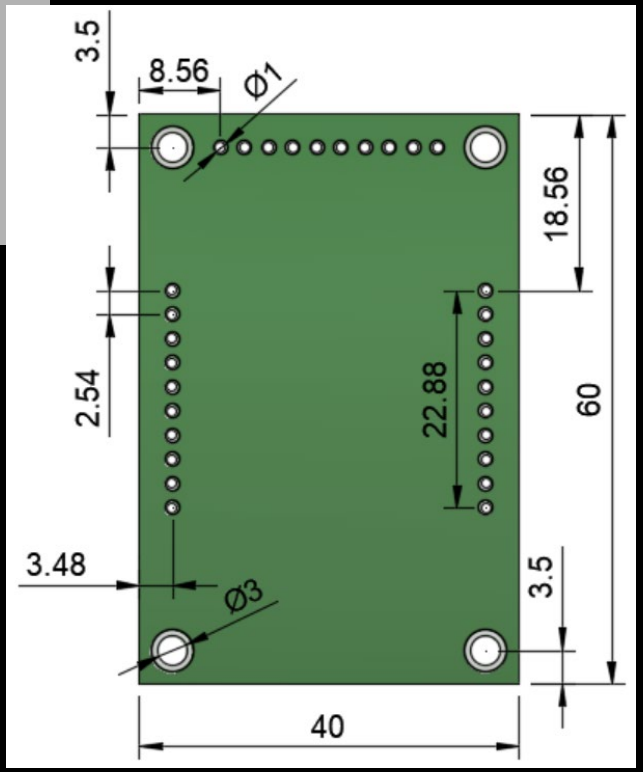
Development – Device Assembly Concept

- Rudimentary Board Planning
  - Determined Board Final Dimensions (40mm x 60mm)
  - Two Stacked PCBs joined by 2.54mm pitch M/F Headers





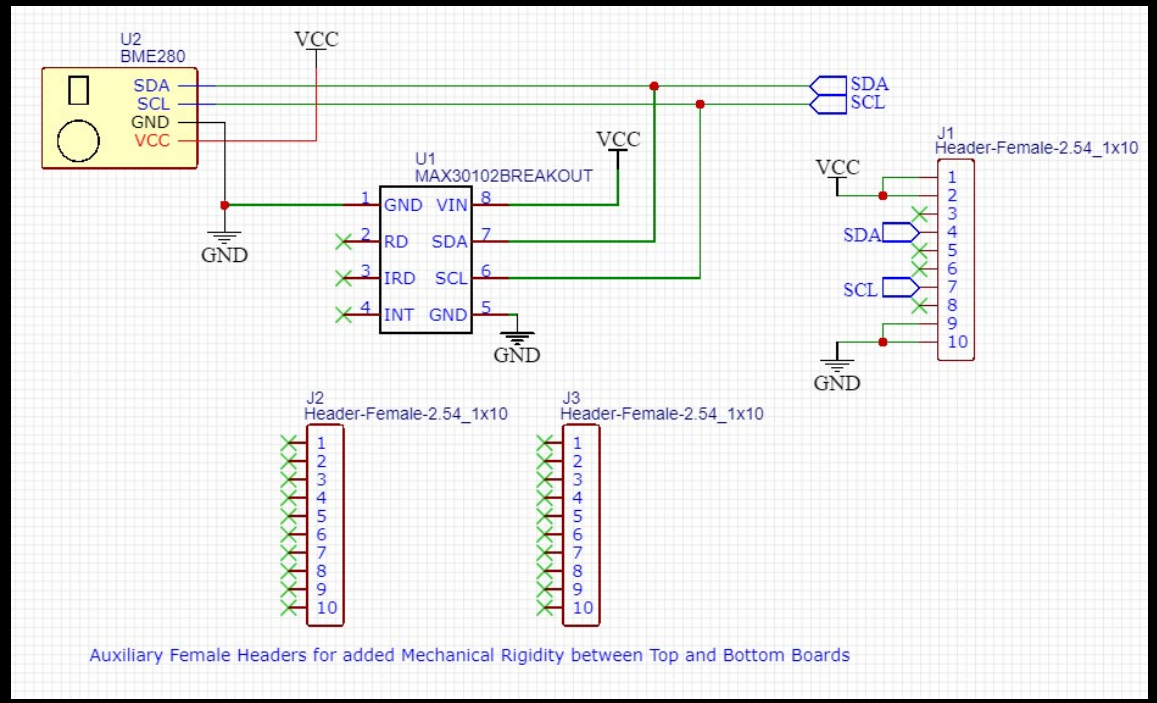


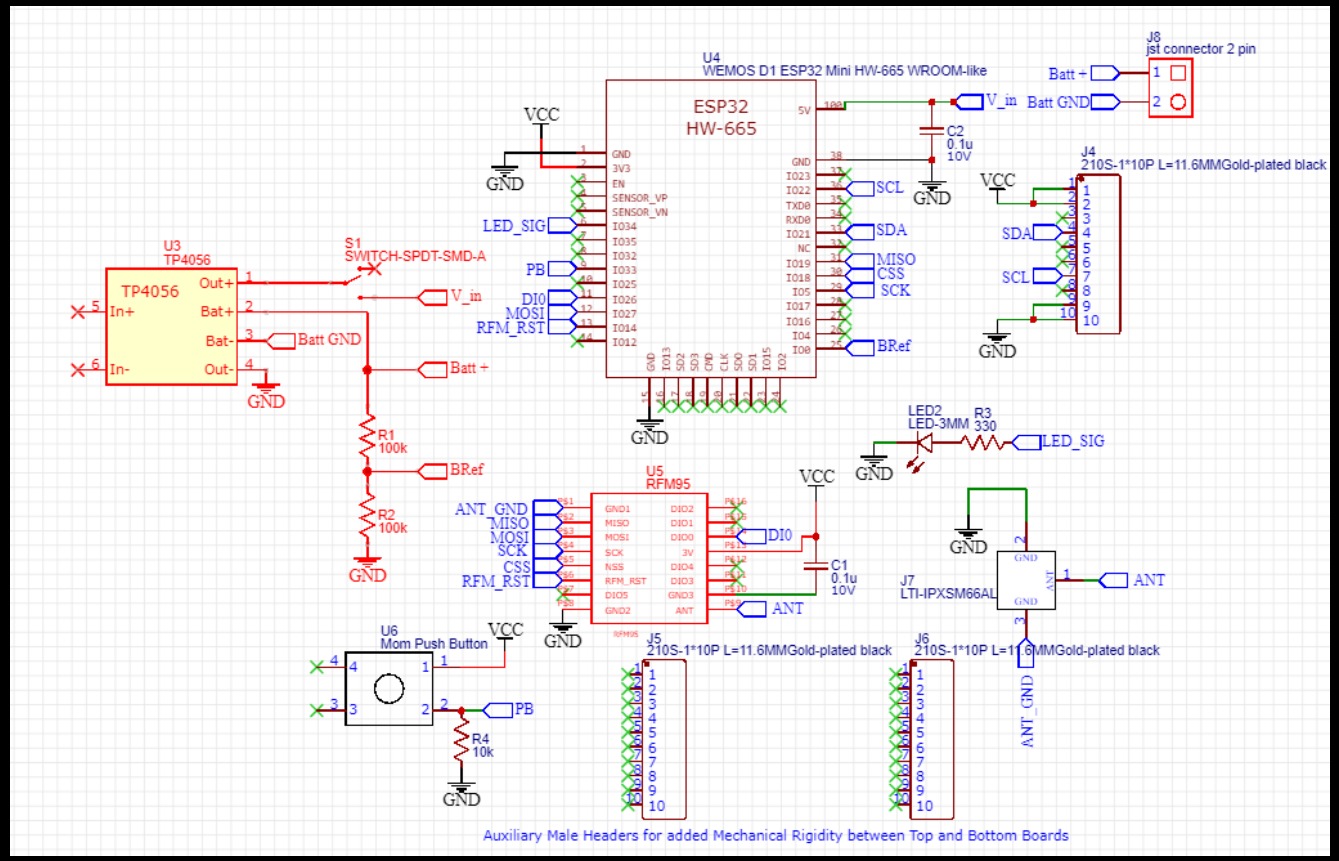


Development - Schematic Design

- Schematic made with EasyEDA

Bottom PCB

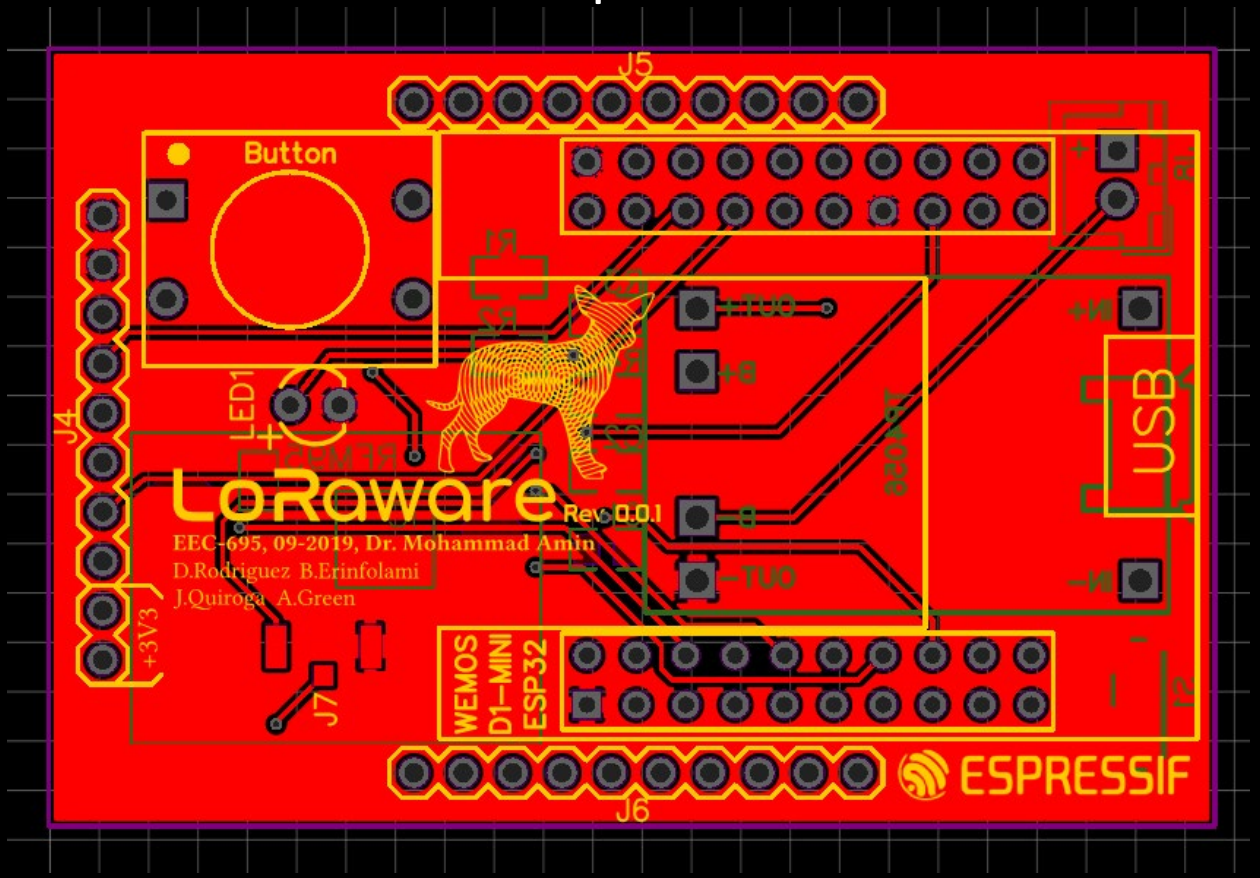




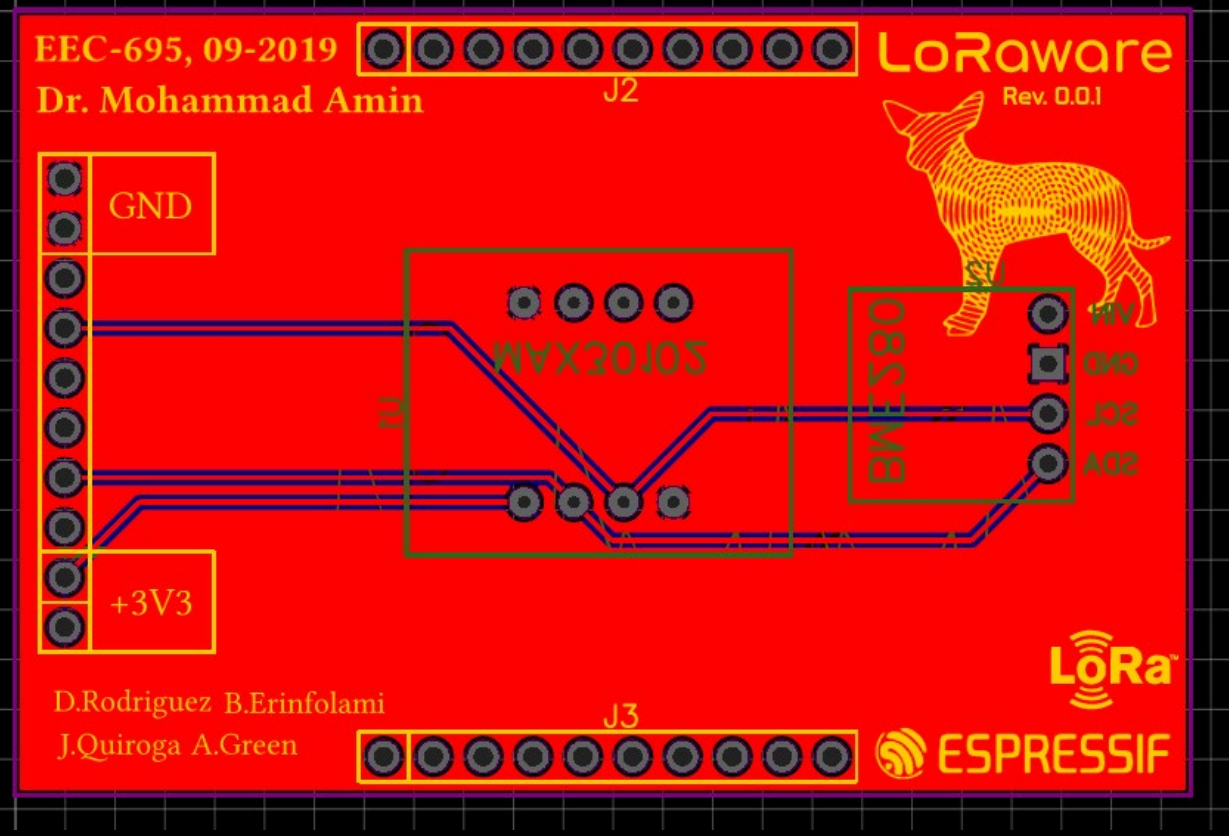
Top PCB

Development – PCB Pre-Fab Design (EasyEDA)

Top PCB



Bottom PCB



Development – PCB Fabrication (JLC PCB)

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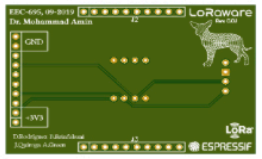
Your order has been approved and put into production. You can review your order status at any time by logging into your JLCPCB Account and viewing your order history.



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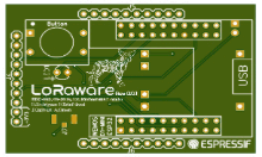
Approved



Gerber_Top-Board_V1_2019090115...

Approved

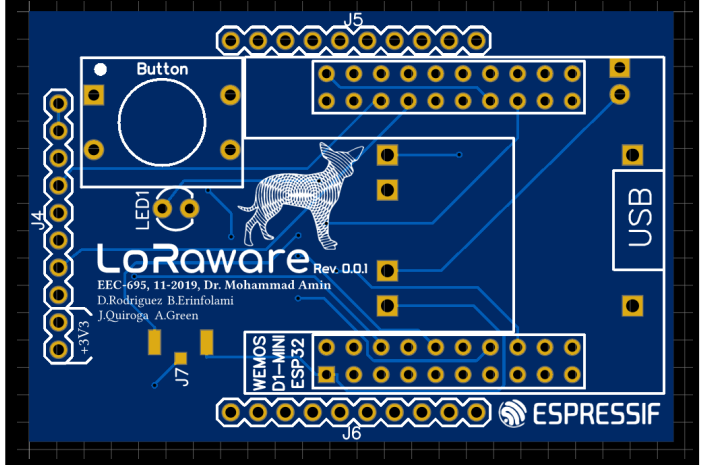
View order details>>

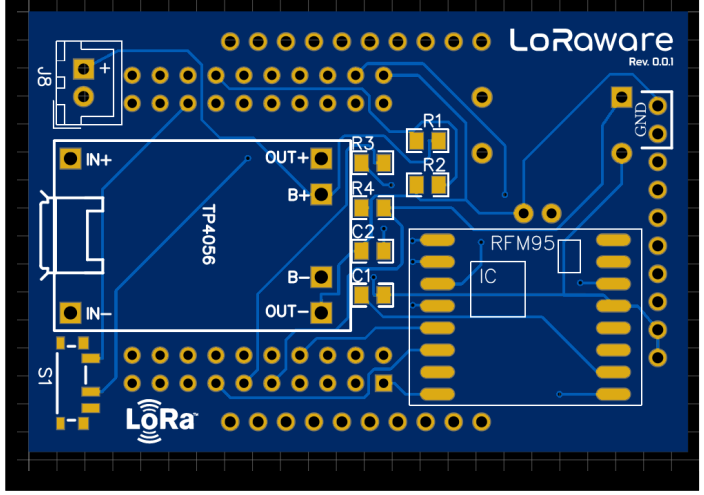
This is an automatically generated email – please do not reply to it. If you have any queries regarding your order please email support@jlcpcb.com.

JiaLiChuang (HongKong) Co., Limited

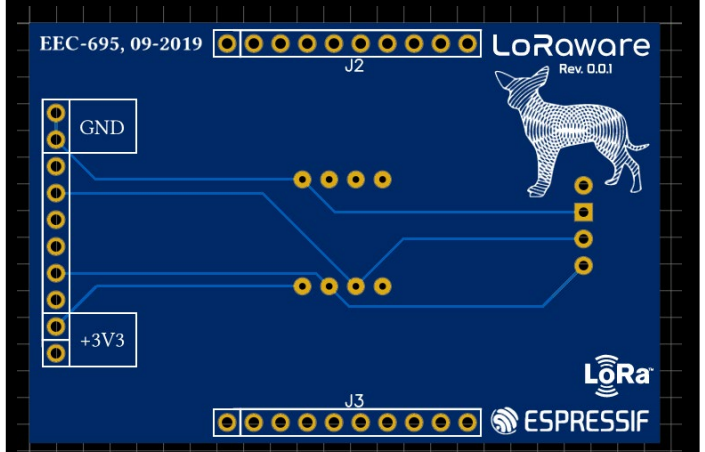
w: JLCPCB.COM

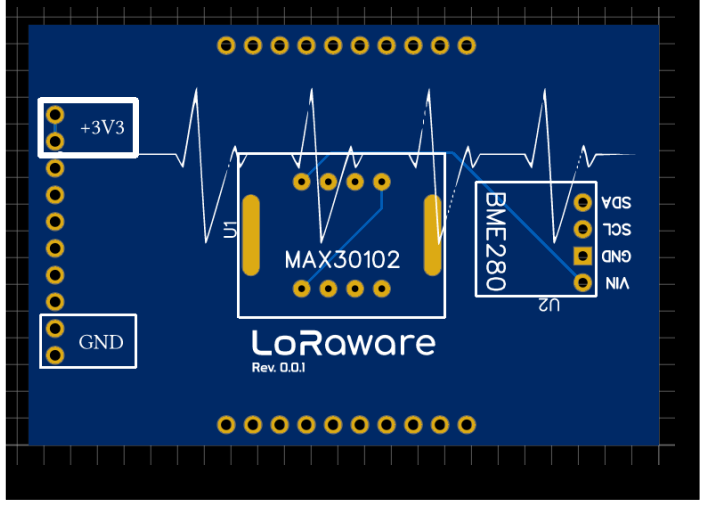
Top PCB



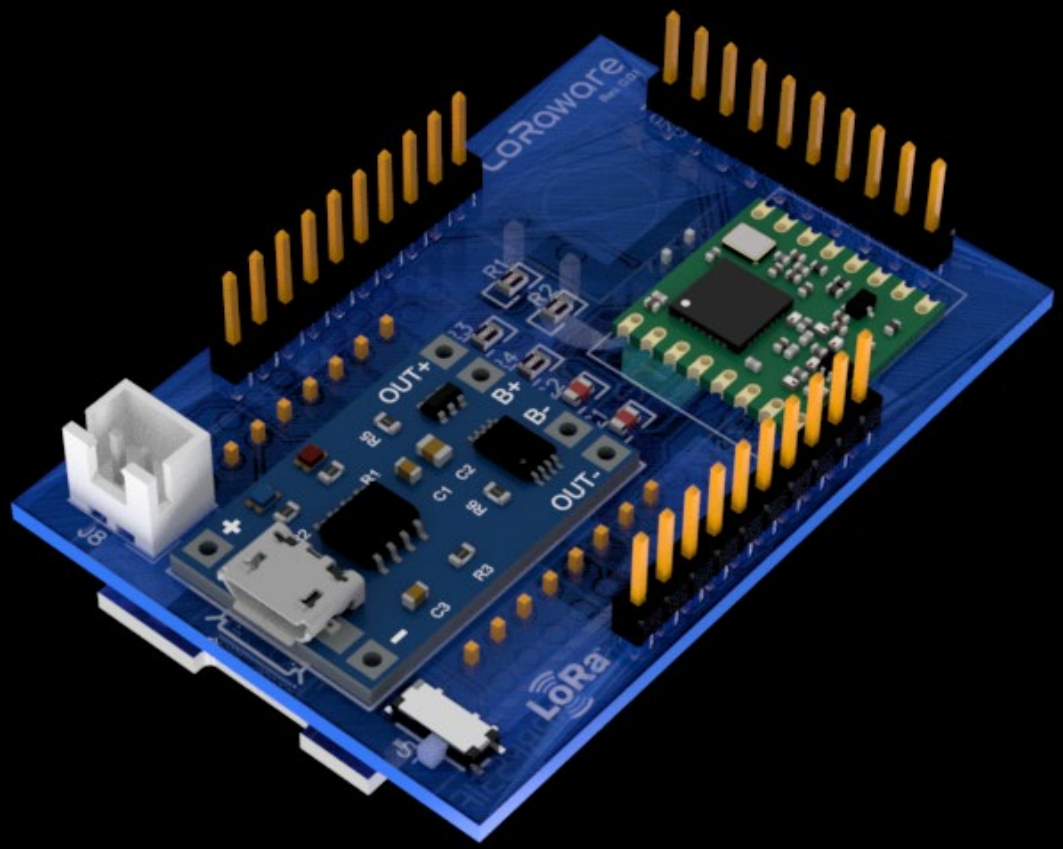


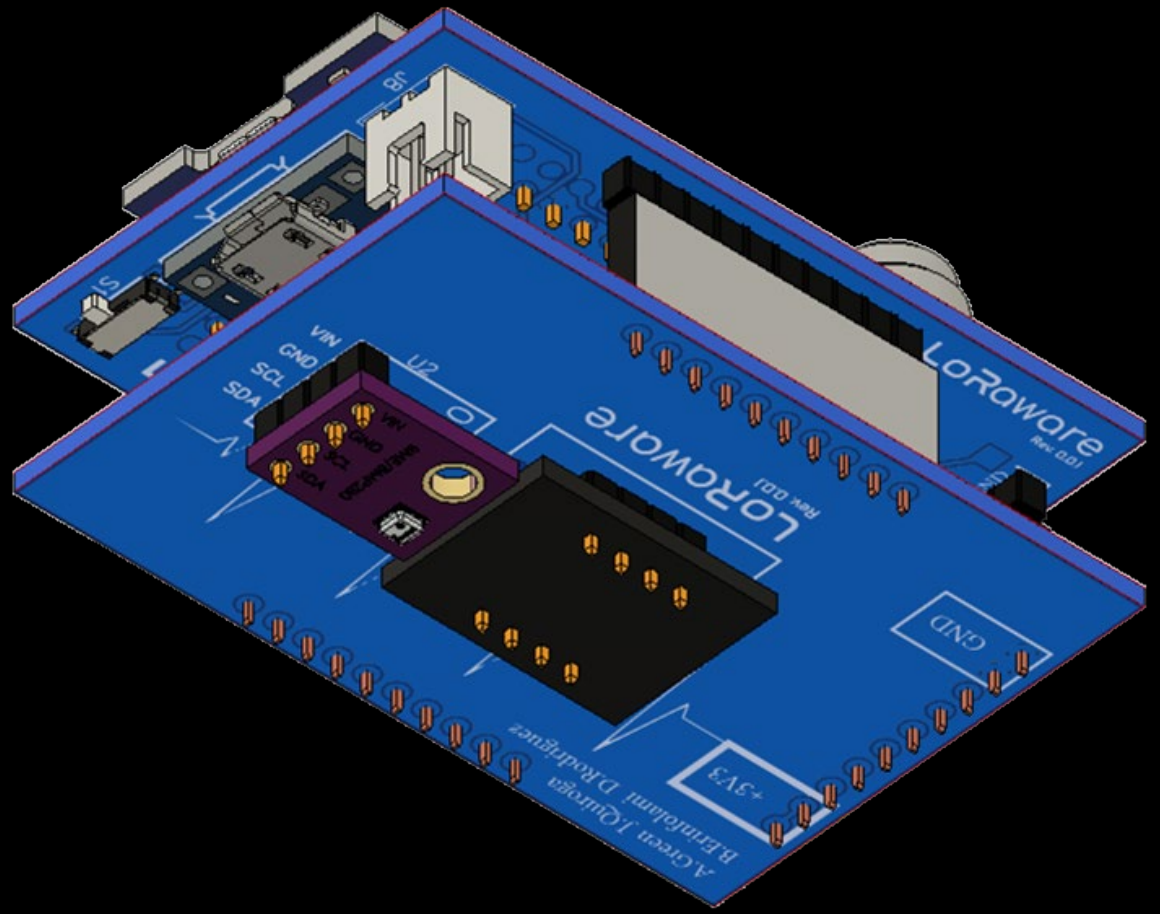
Bottom PCB



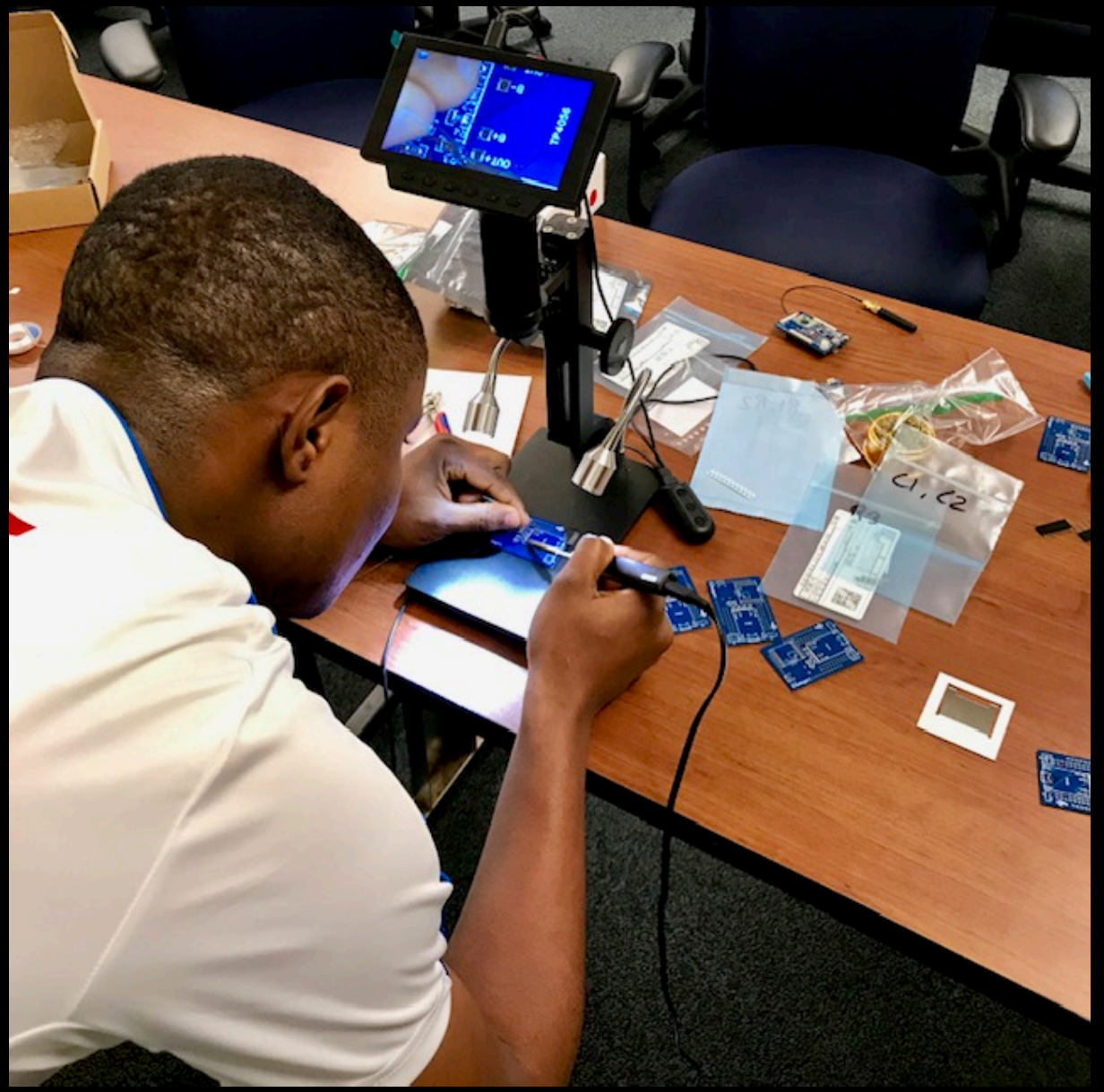


Development – Component Assembly

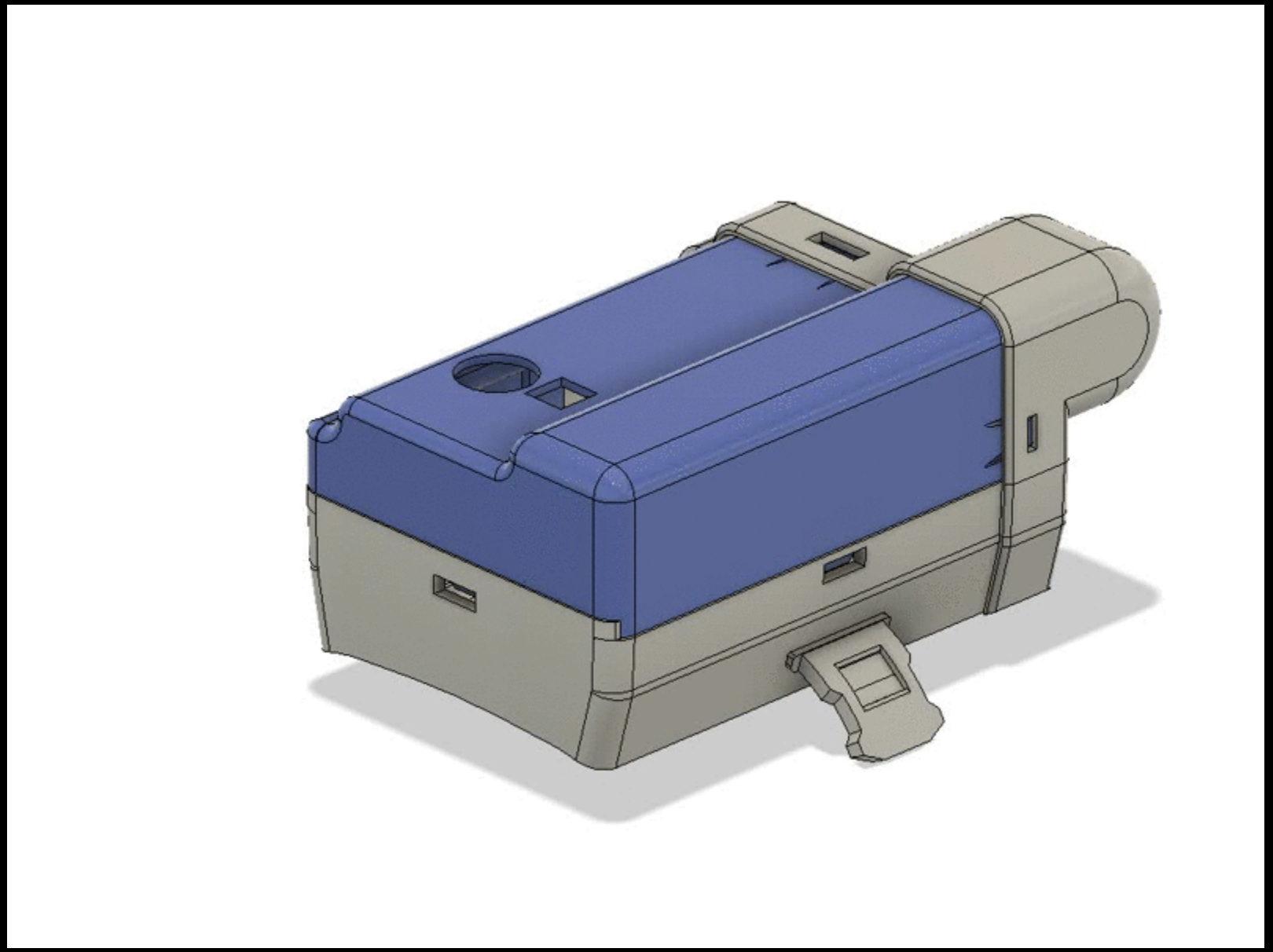




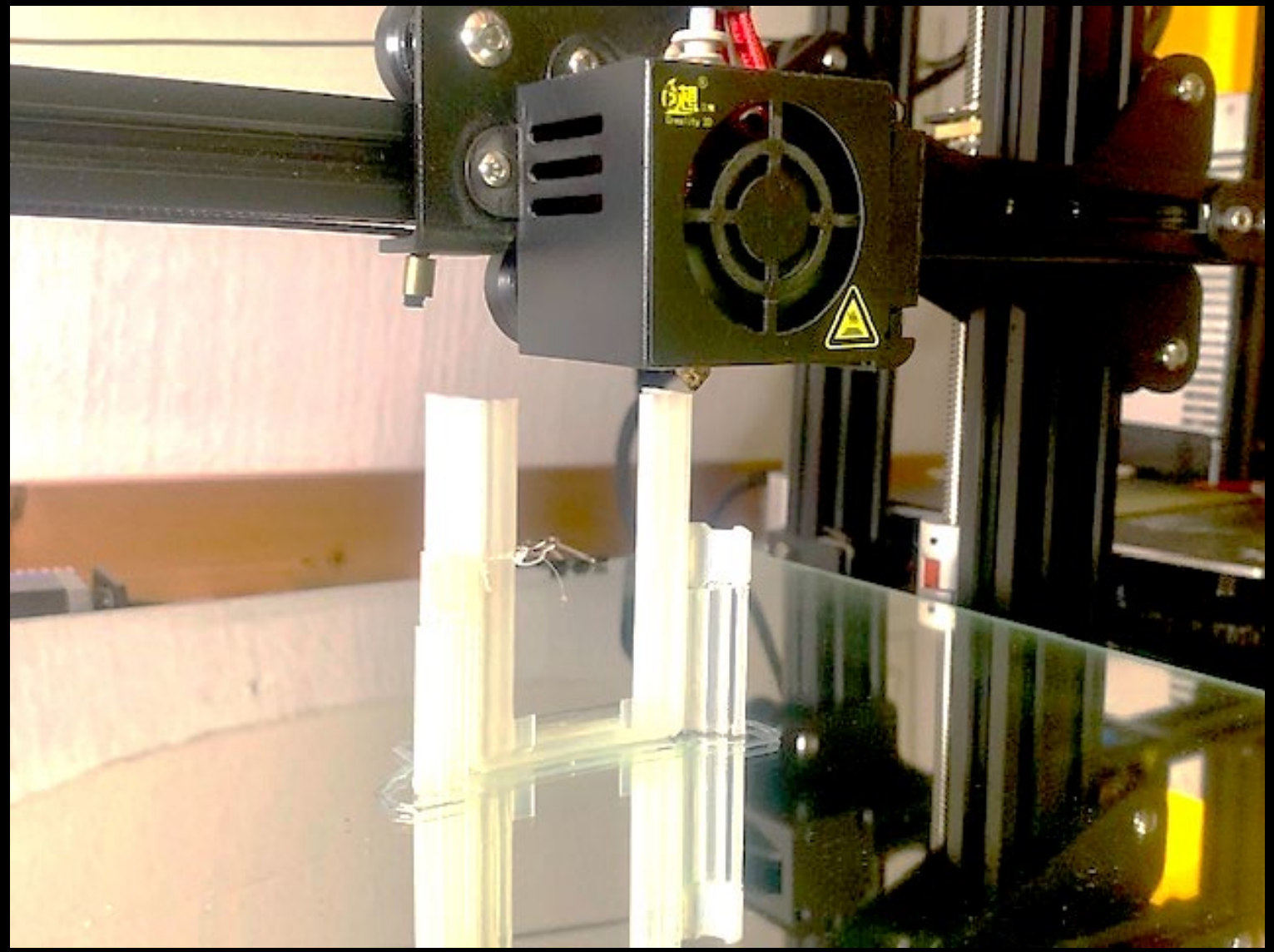
Development – Board Assembly Day



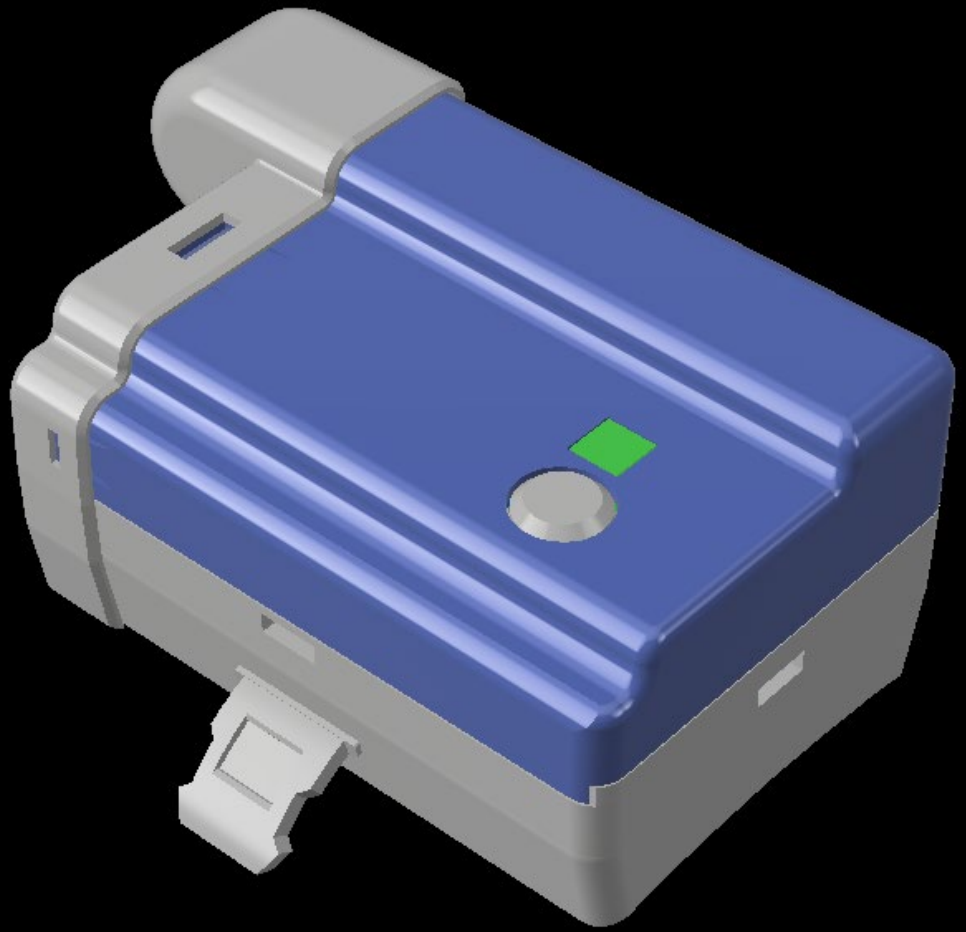
Development - Enclosure CAD Design

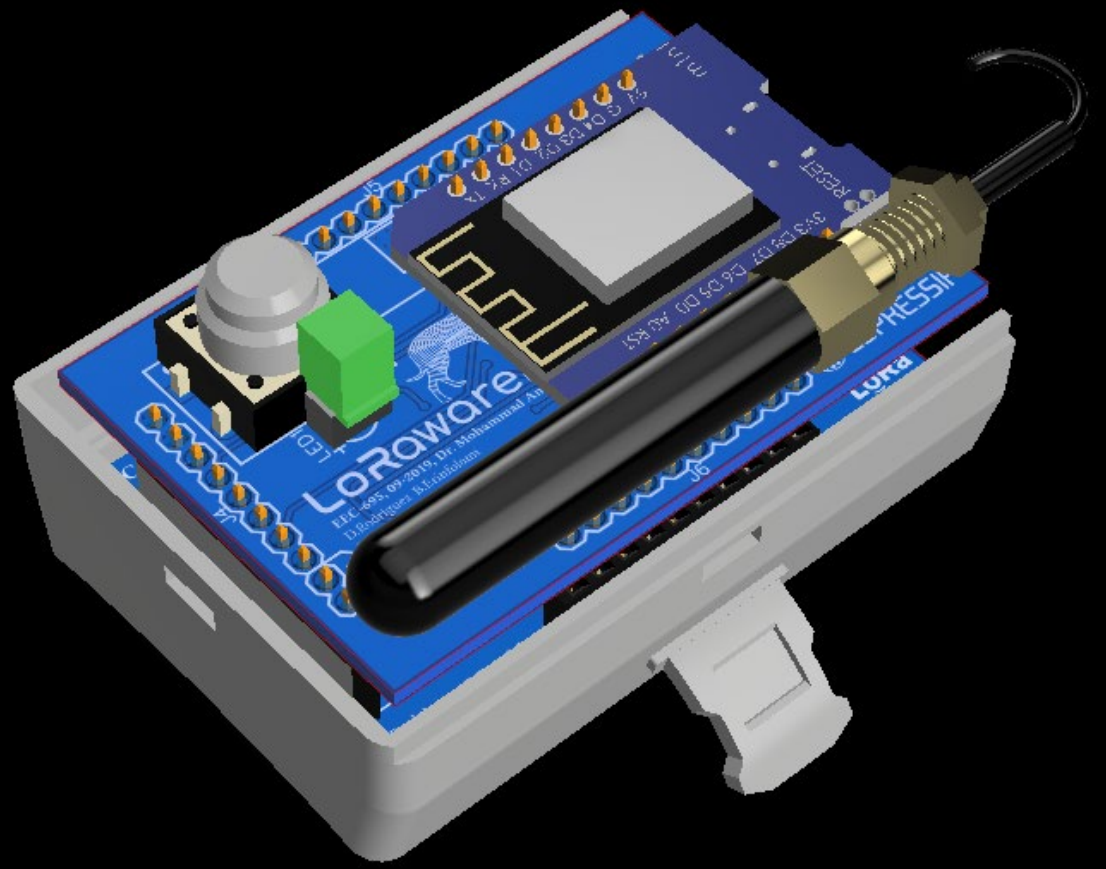


Development – Enclosure Manufacturing



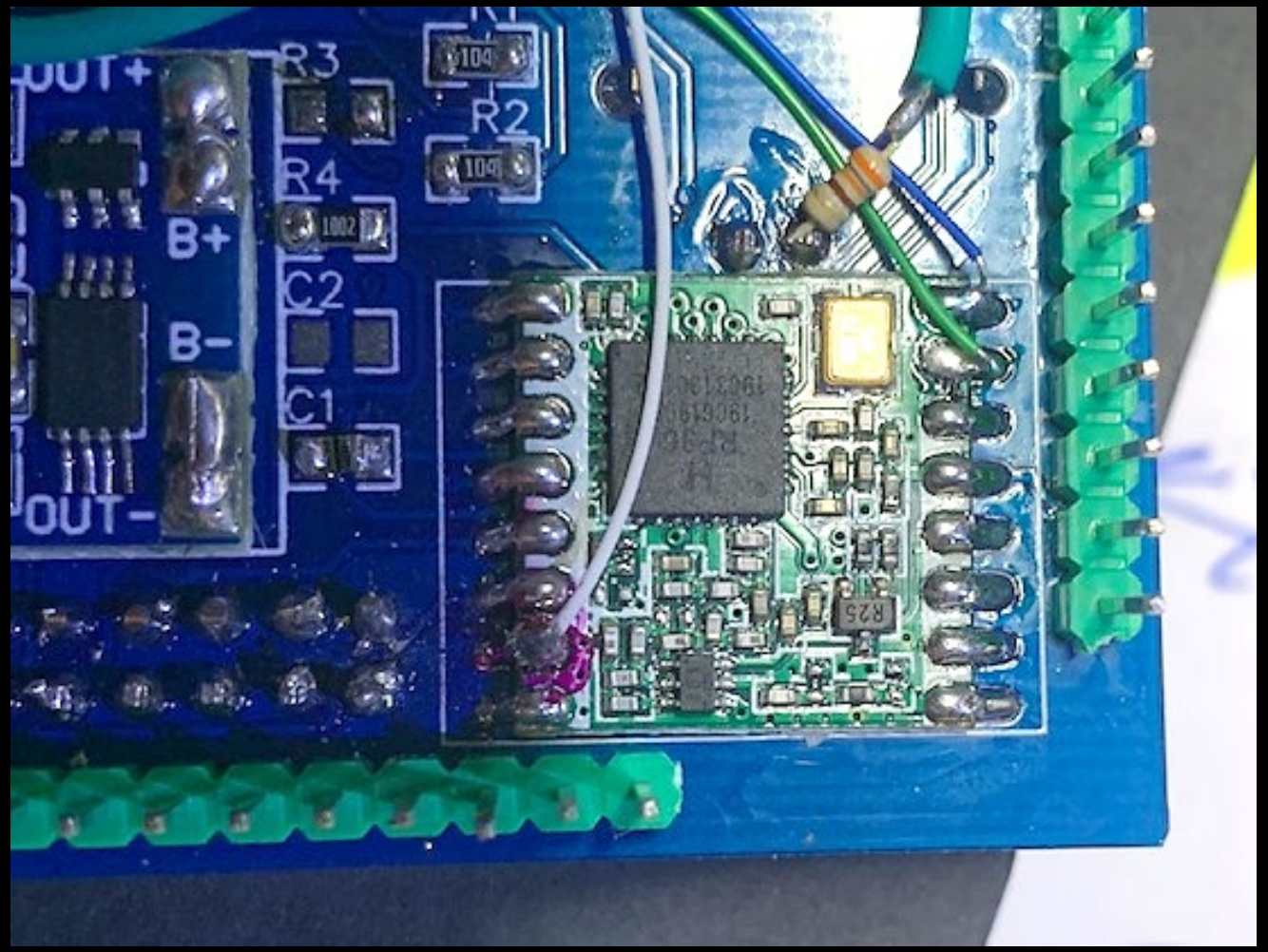
Development – Enclosure Assembly





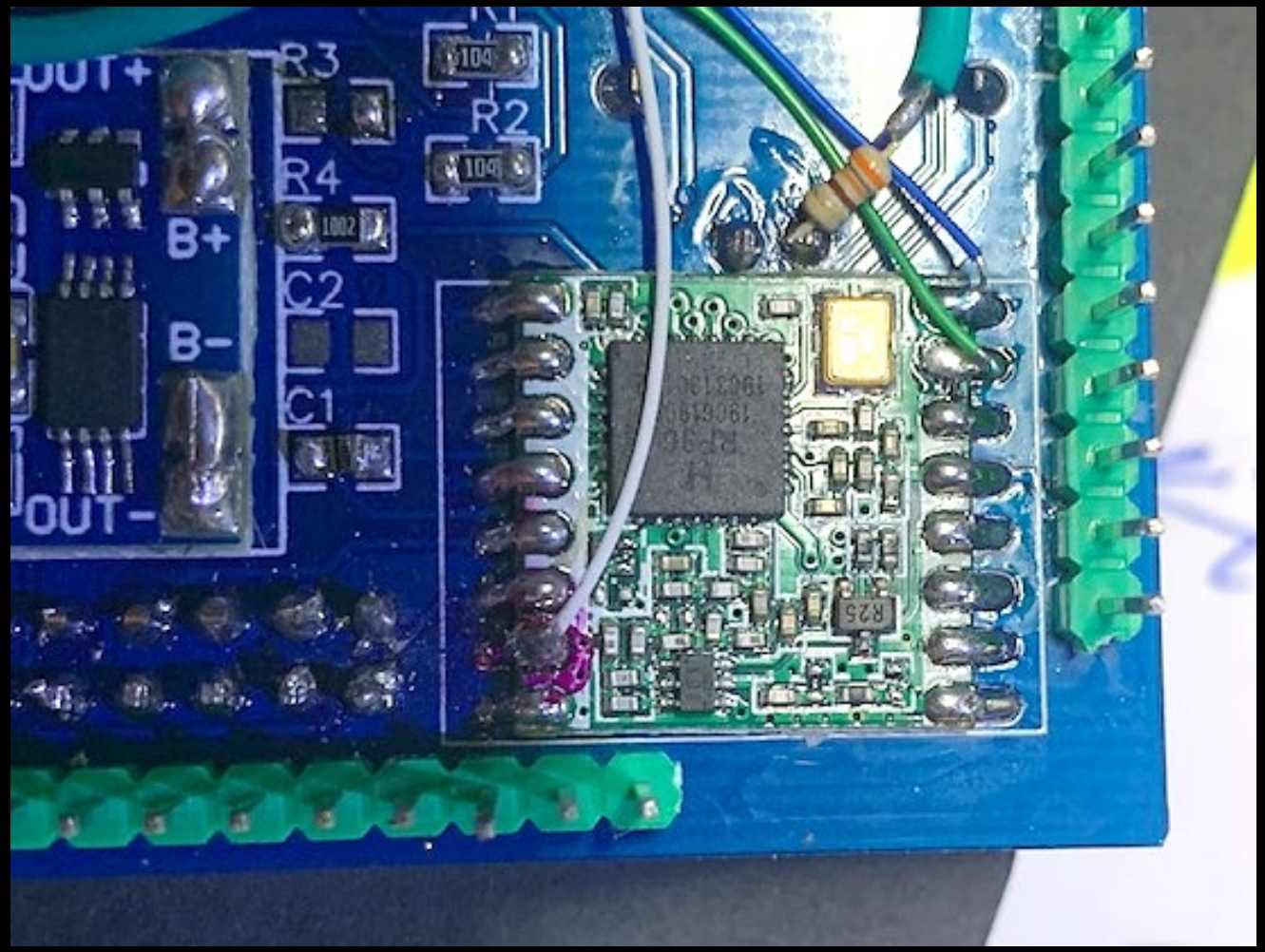
Development – LoRaWAN Roadblocks

- Small Board Errors
  - RFM95 required three more Interrupt Pins to enable Full LoRaWAN Capabilities
  - Onboard voltage regulator dropout when Battery Voltage Applied



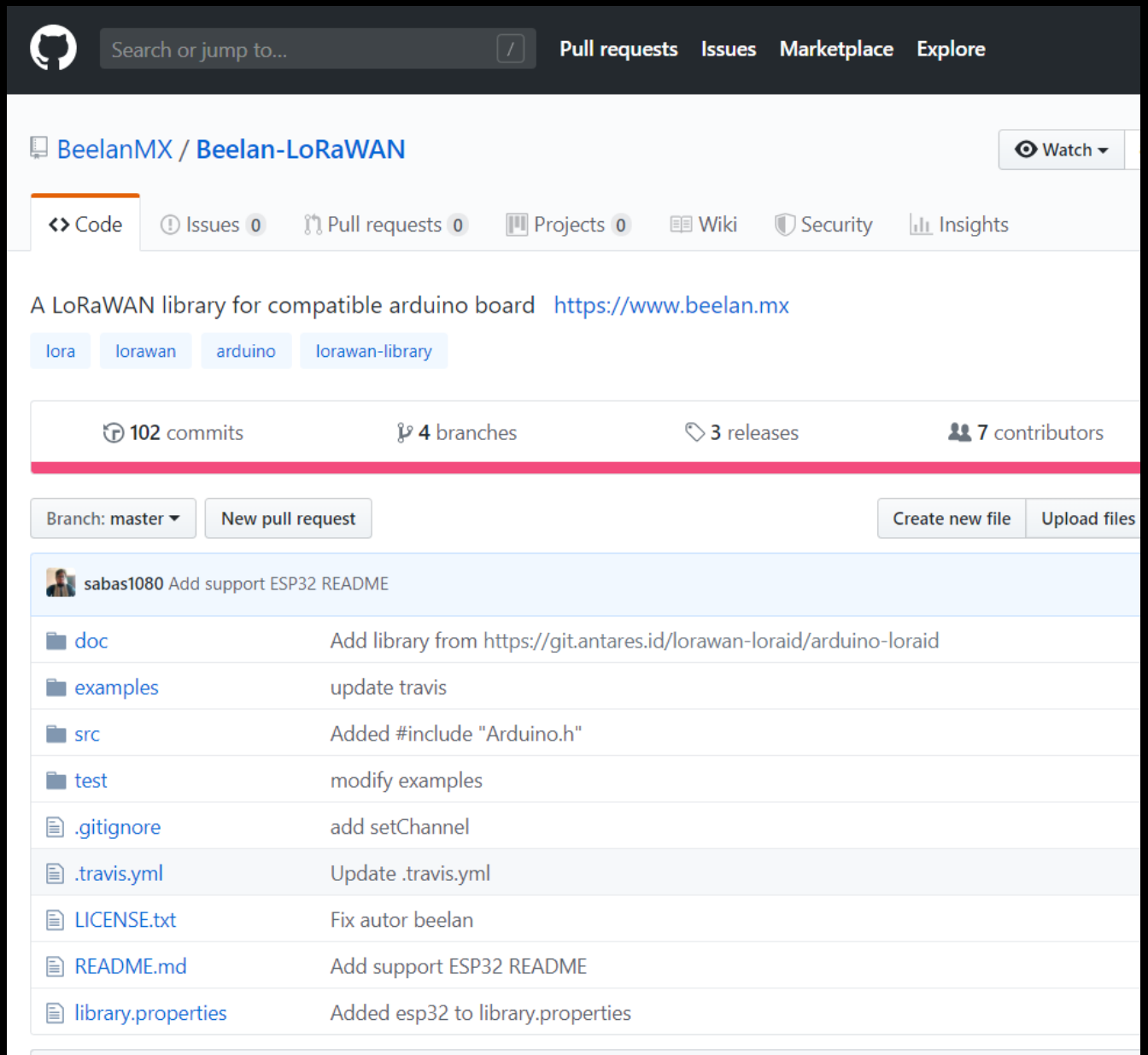
Development – LoRaWAN Roadblocks

- Small Board Errors
  - Resolved by cutting 5V trace on PCB and bypassing with external 30 Gauge Kynar Wires

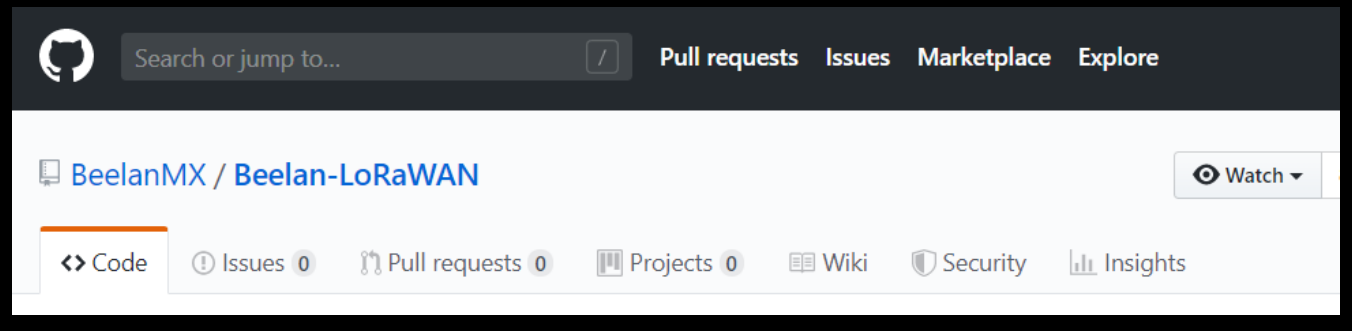


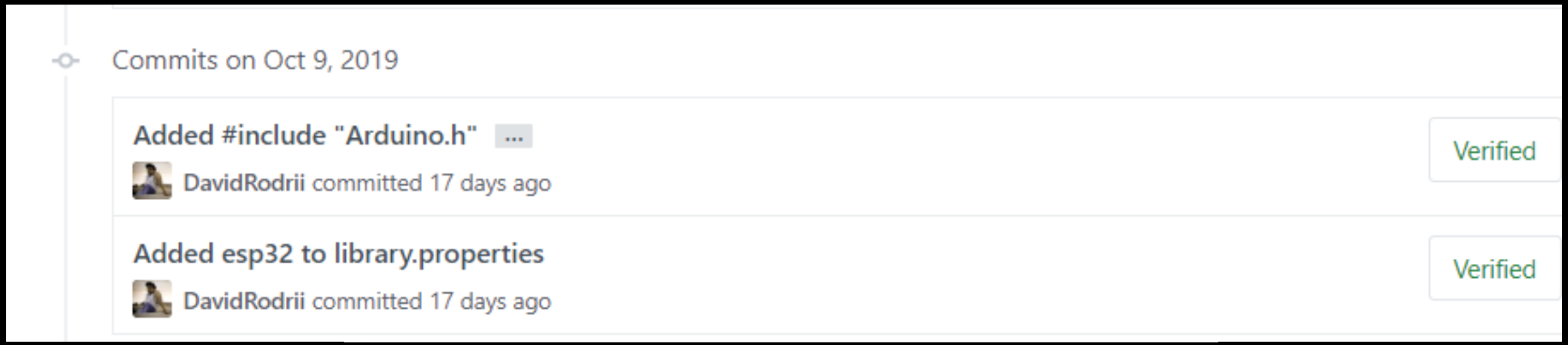
Development – LoRaWAN Roadblocks

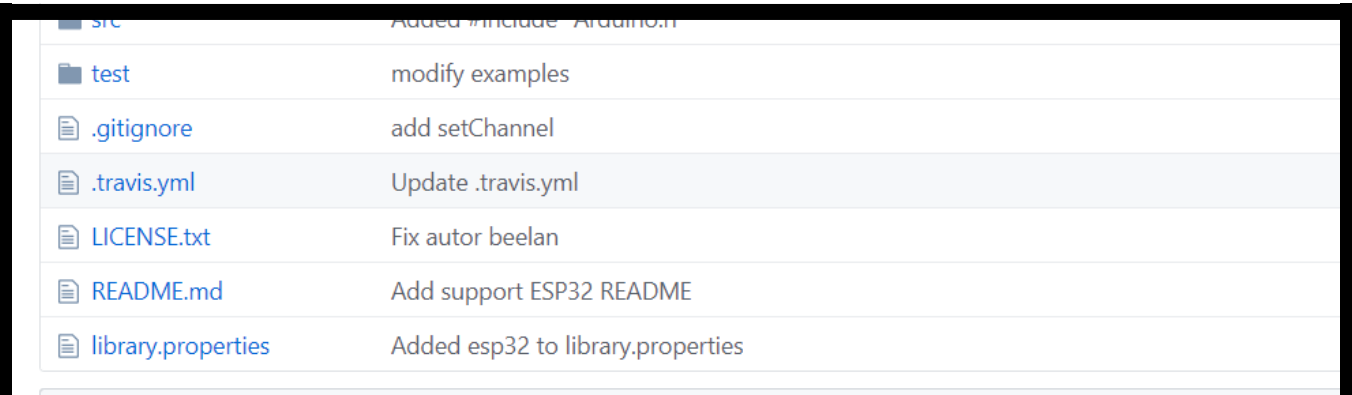
- Arduino LoRaWAN Library for US-915 MHz was incompatible with ESP32 Architecture
    - Produced Errors when Flashing LoRaWAN Communication Firmware to LoRaware Devices



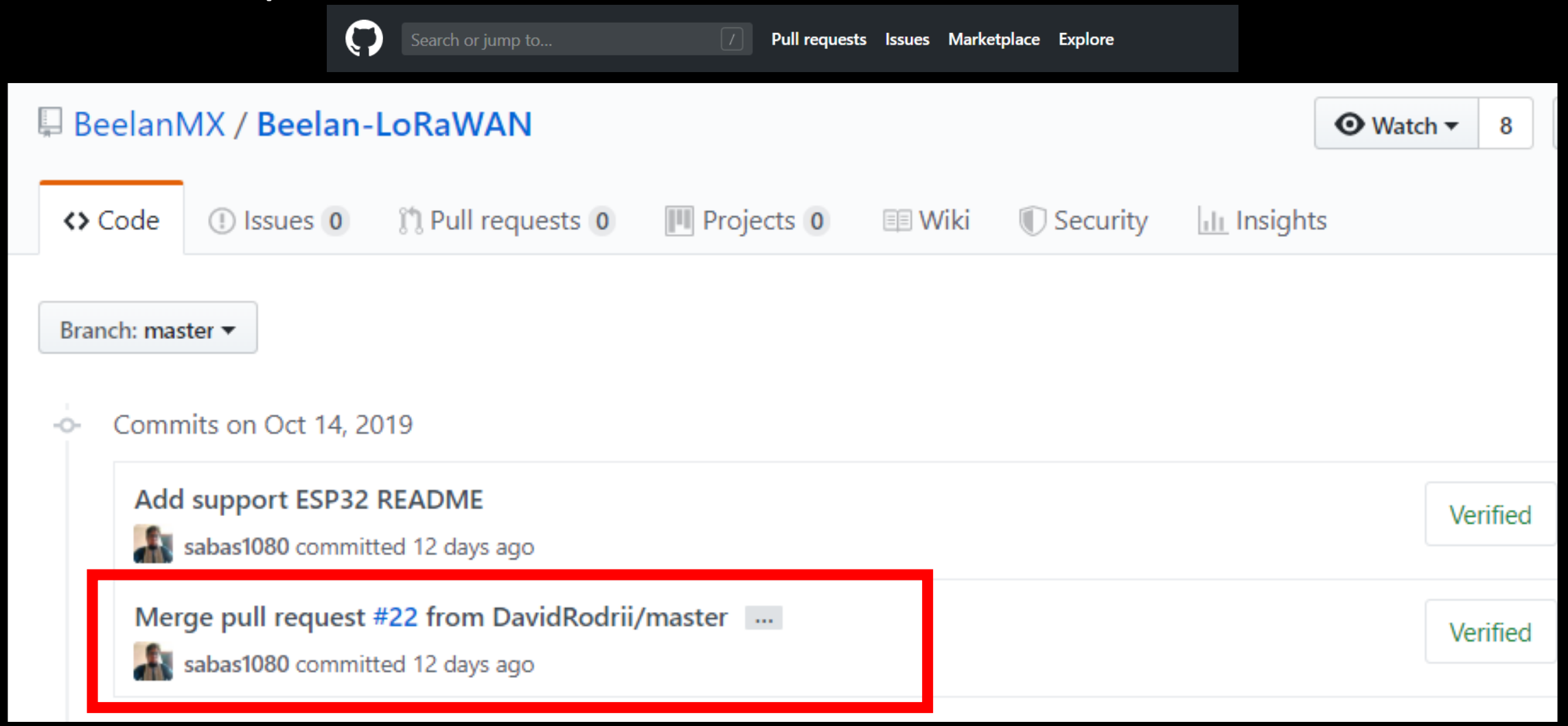
Development – LoRaWAN Roadblocks





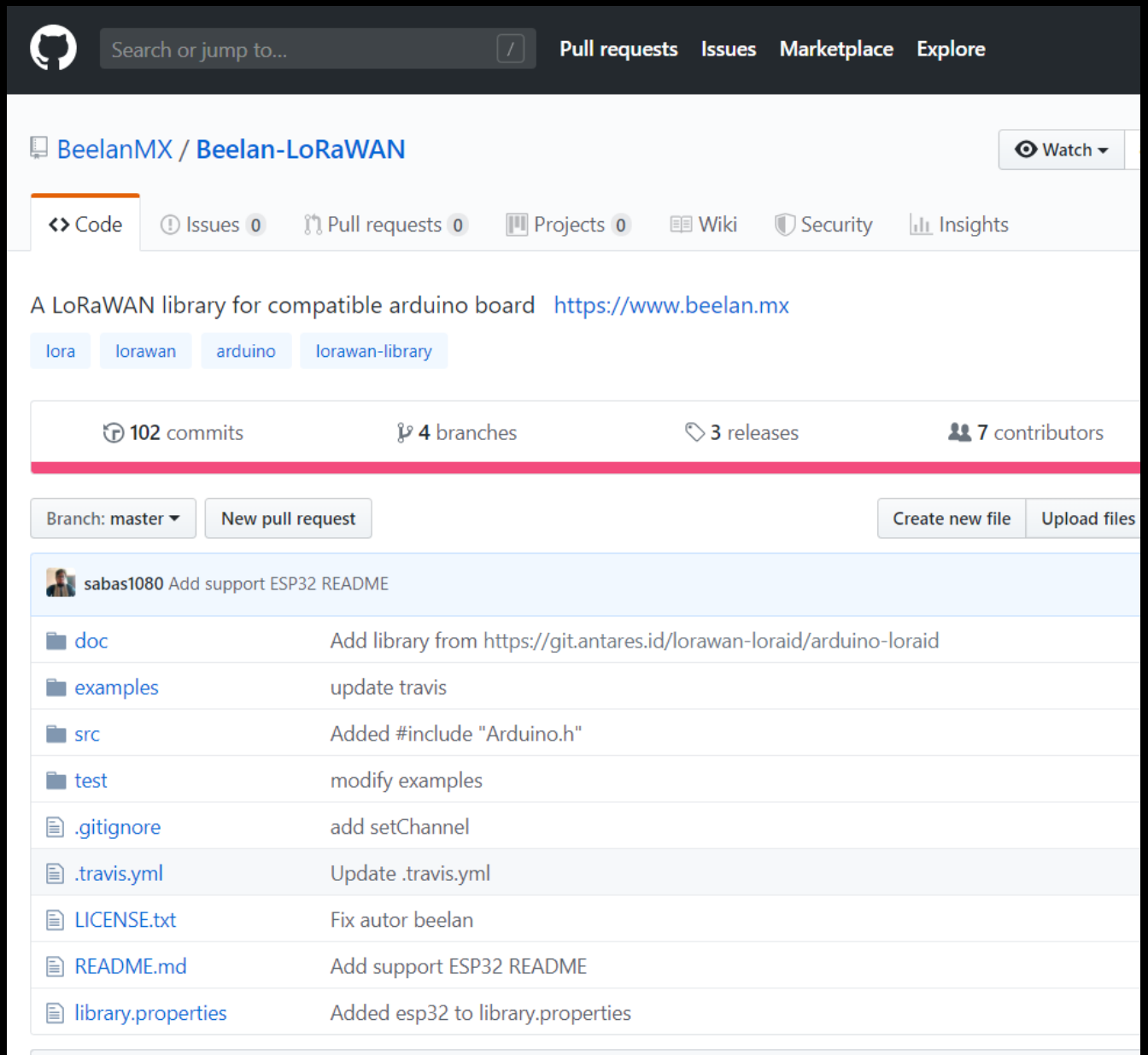


Development – LoRaWAN Roadblocks



Development – LoRaWAN Roadblocks

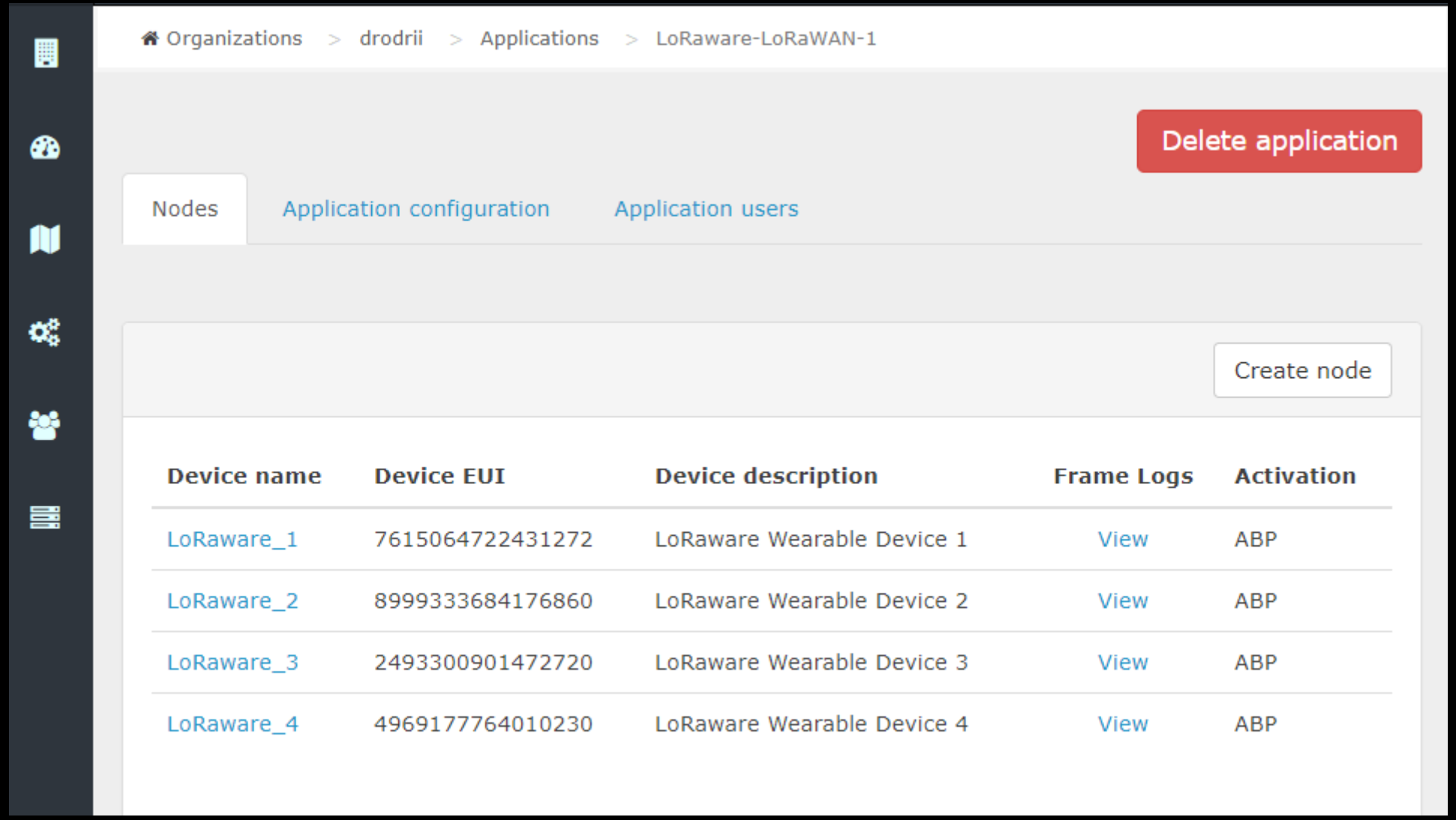
- Resolved after editing source files with incremental changes and monitoring C++ Compilation Errors
- Our edits were pushed to the Library's Github Repository in the form of a Pull Request
- Our changes received approval from Repository Maintainers and were merged into the Master Build
- https://github.com/BeelanMX/Beelan-LoRaWAN



Development – Gateway Configuration

- Supports entire LoRaWAN Network
- Operates as Wi-Fi Access Point
- Gateway Default Application – Forwards LoRaWAN Packets to Published MQTT Messages within IEEE 802.11 Network

Development - LoRaWAN Gateway Management



Development – LoRaWAN Proof of Concept

pi@raspberrypi: ~/MatchX


```
,"codeRate":"4/5"},"fCnt":532,"fPort":1,"data":"Q291bnRlci01MzI="}
^C
pi@raspberrypi:~/MatchX $ mosquitto sub -h usx.matchx.io -p 8883 -t "#" -v --caf
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```


debug

all nodes

msg.payload : Object

{ applicationID: "24", applicationName: "LoRaWAN-Test1", nodeName: "TBEAM-NoOLED", devEUI: "2687614411400960", rxInfo: array[1] … }

9/3/2019, 8:45:10 PM node: be860696.207518

application/24/node/2687614411400960/rx :

msg.payload : Object

{ applicationID: "24", applicationName: "LoRaWAN-Test1", nodeName: "TBEAM-NoOLED", devEUI: "2687614411400960", rxInfo: array[1] … }

9/3/2019, 8:45:20 PM node: be860696.207518

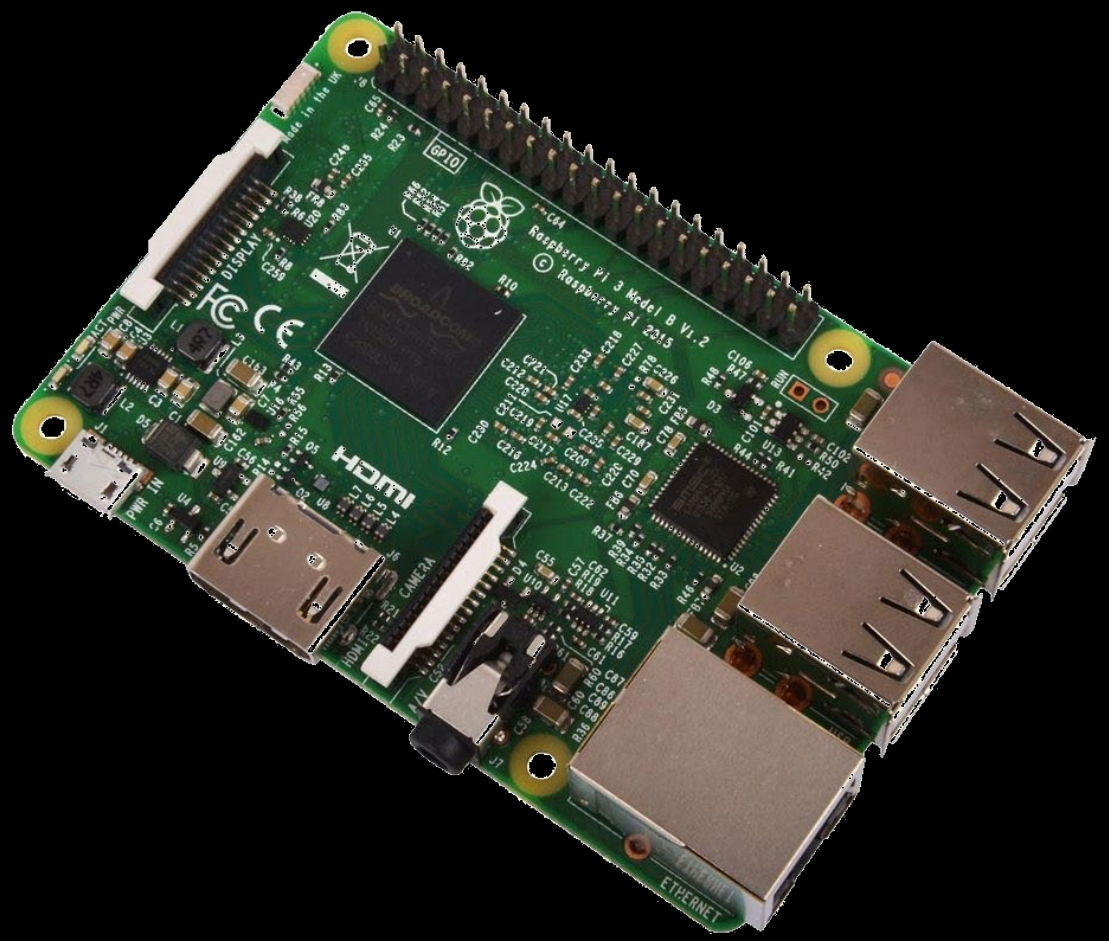
application/24/node/2687614411400960/rx :

msg.payload : Object

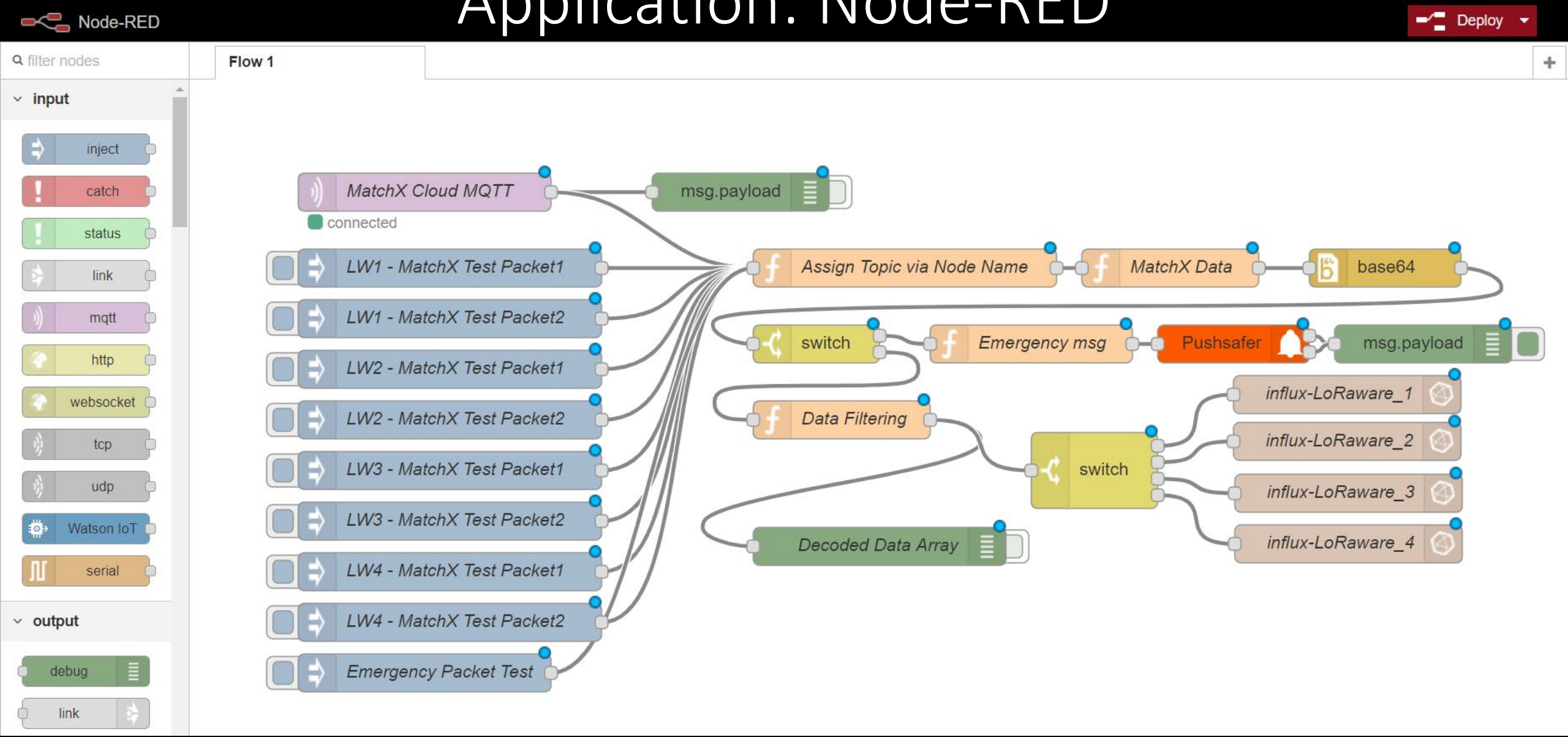
{ applicationID: "24", applicationName: "LoRaWAN-Test1", nodeName: "TBEAM-NoOLED", devEUI: "2687614411400960", rxInfo: array[1] … }

Development – Server & Applications

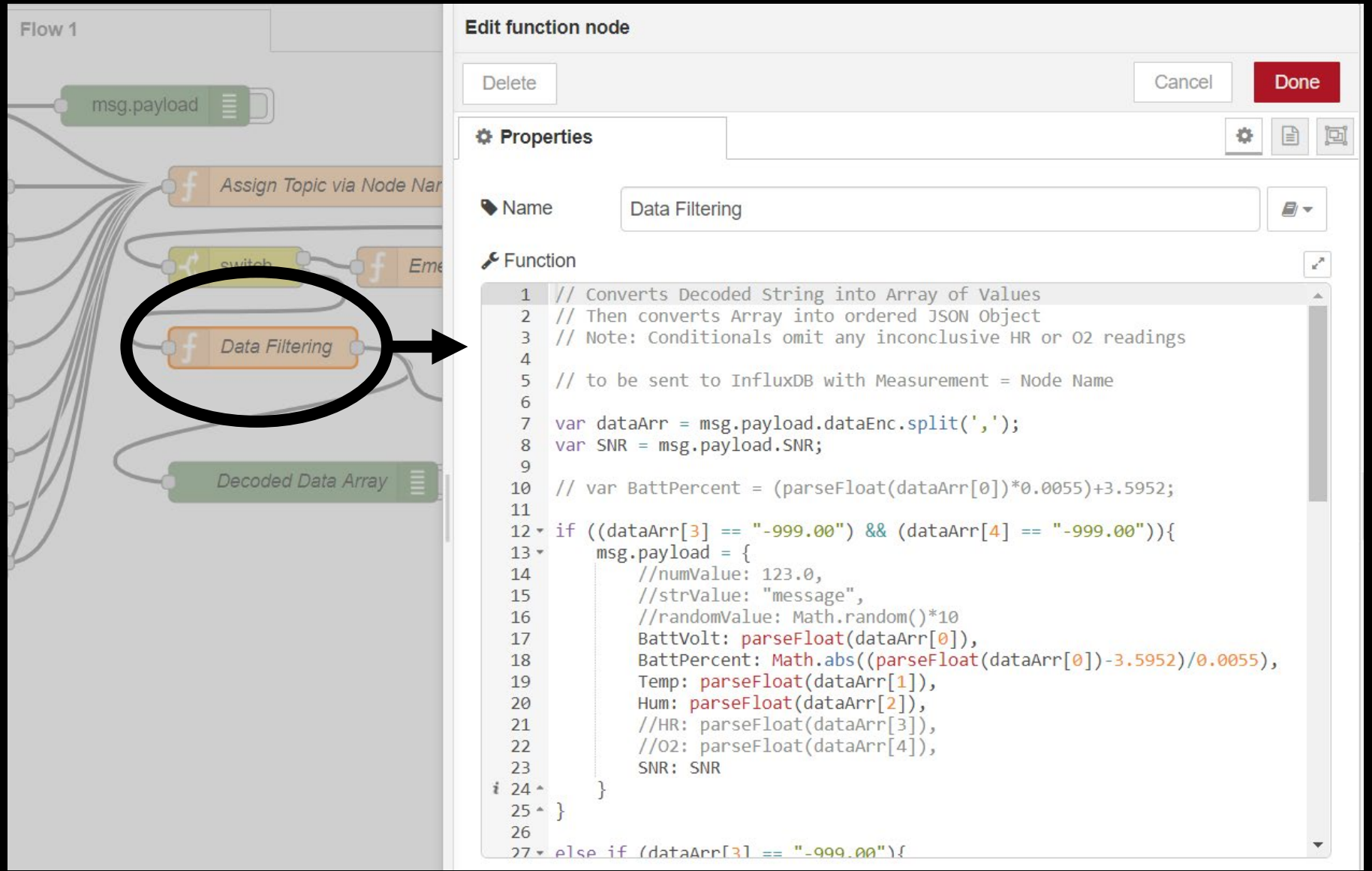
- Connected to Gateway's Independent Wi-Fi Network
- Subscribed to Gateway's MQTT Messages
- Hosts Node-Red for Data Parsing, conversion, and Database Queries
- Hosts InfluxDB Database
- Hosts Grafana Dashboard



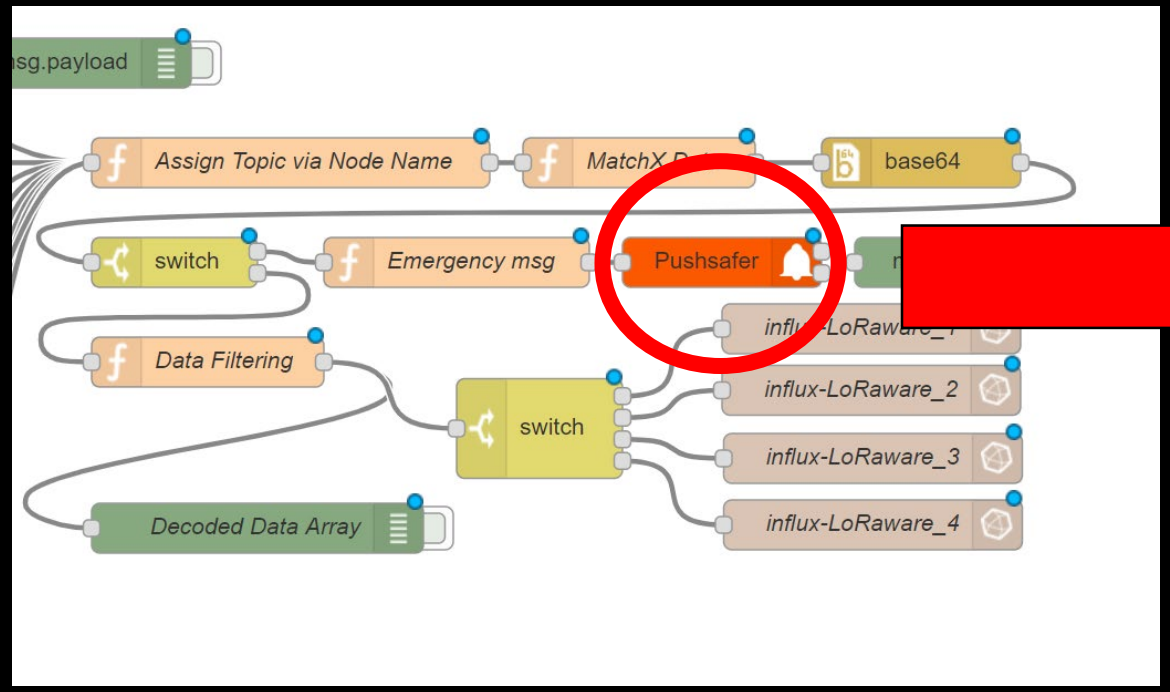
Development – Server-Side Data Parsing Application: Node-RED

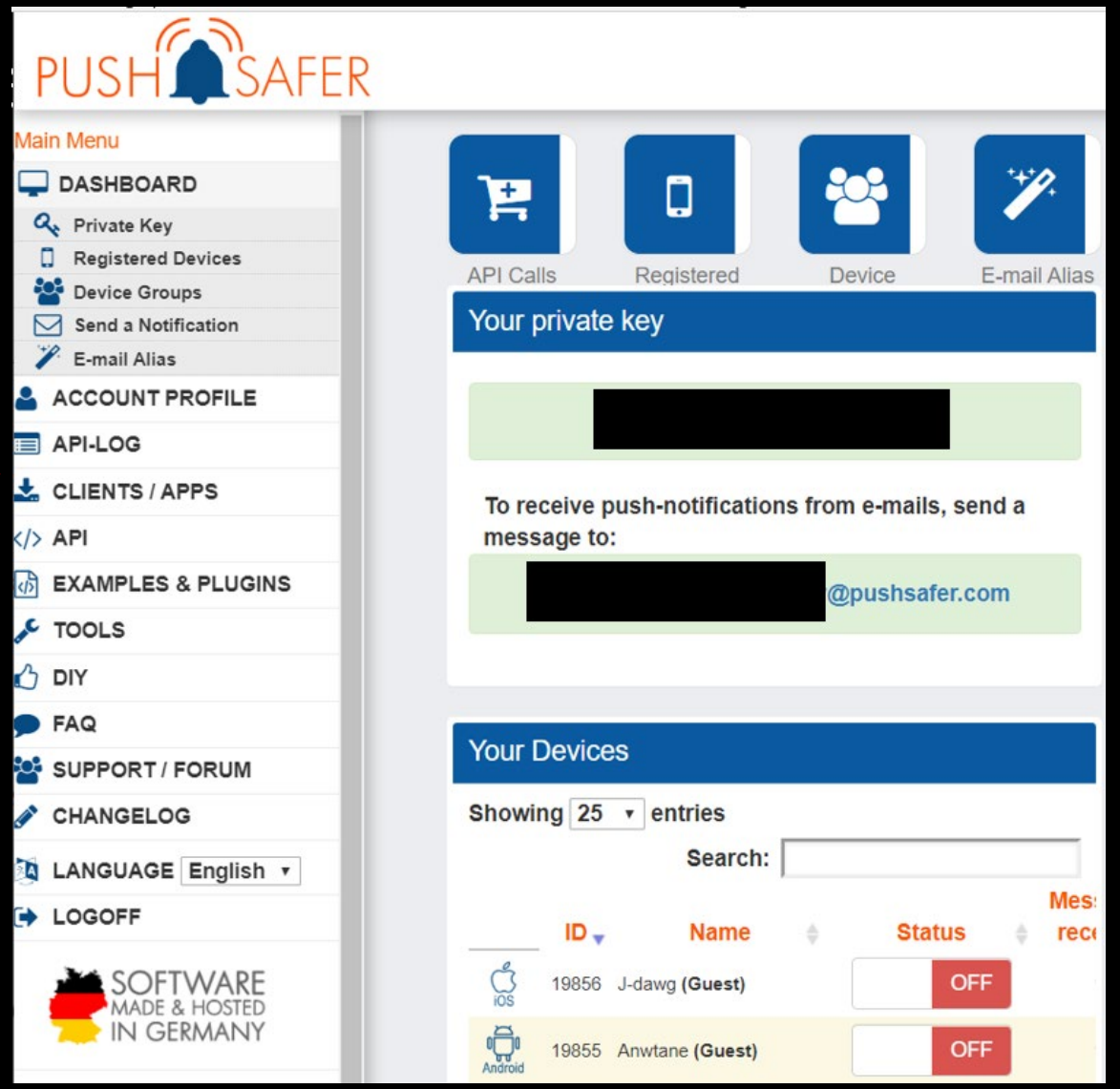


Development – Server-Side Data Parsing Application: Node-RED

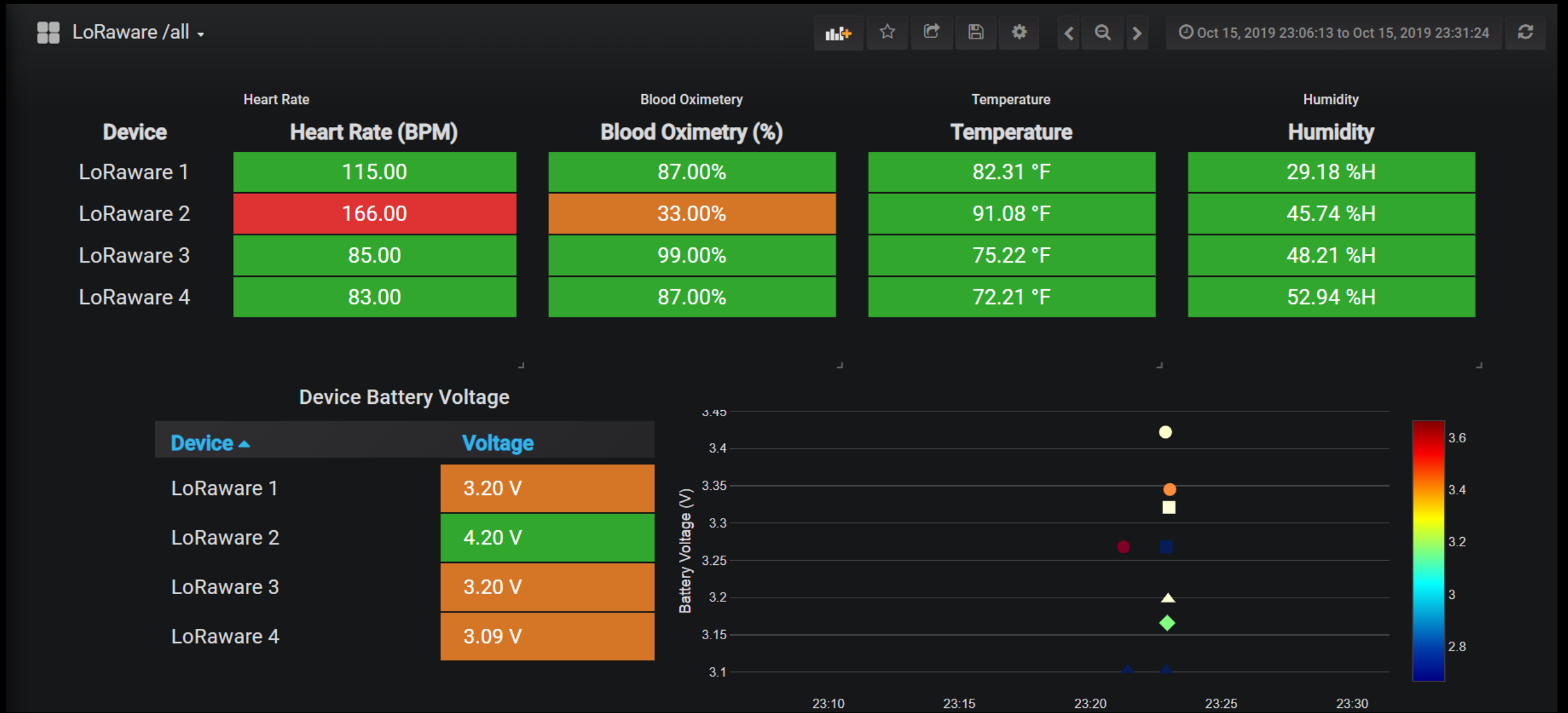


Development – Server-Side Notifications/Alerts Application: Pushsafer



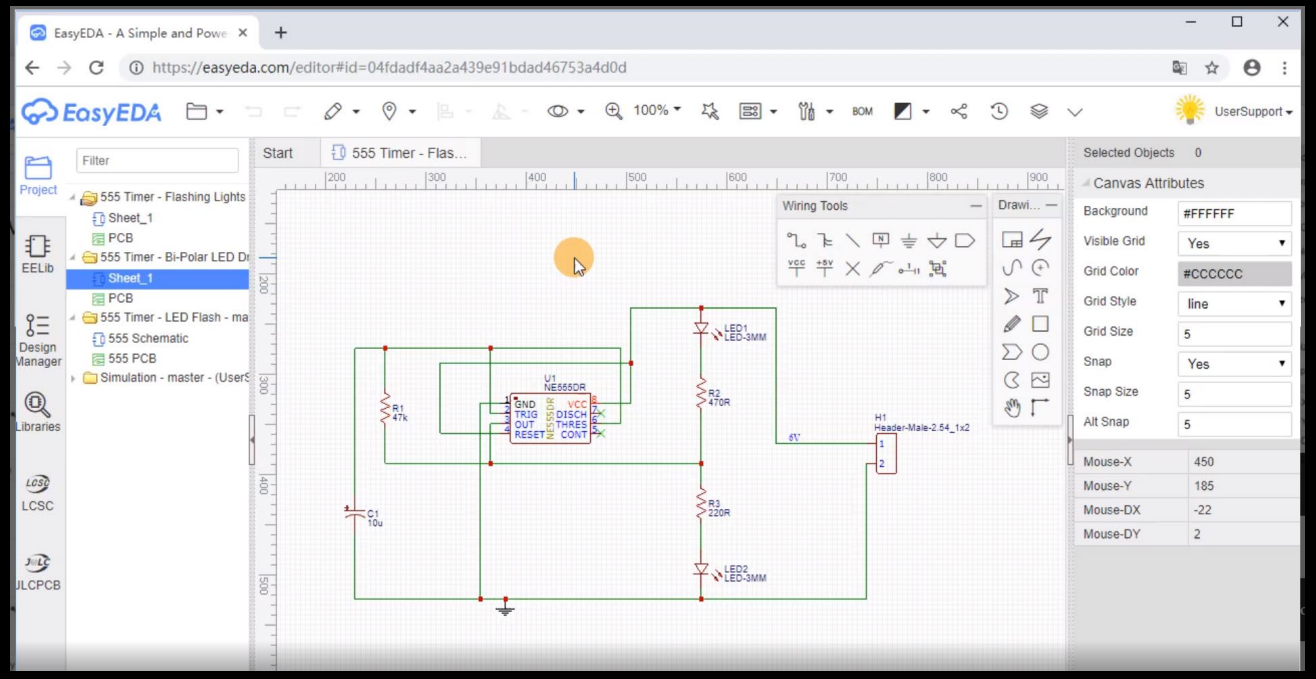


Development – Server-Side Metrics Monitoring Application: Grafana Dashboard

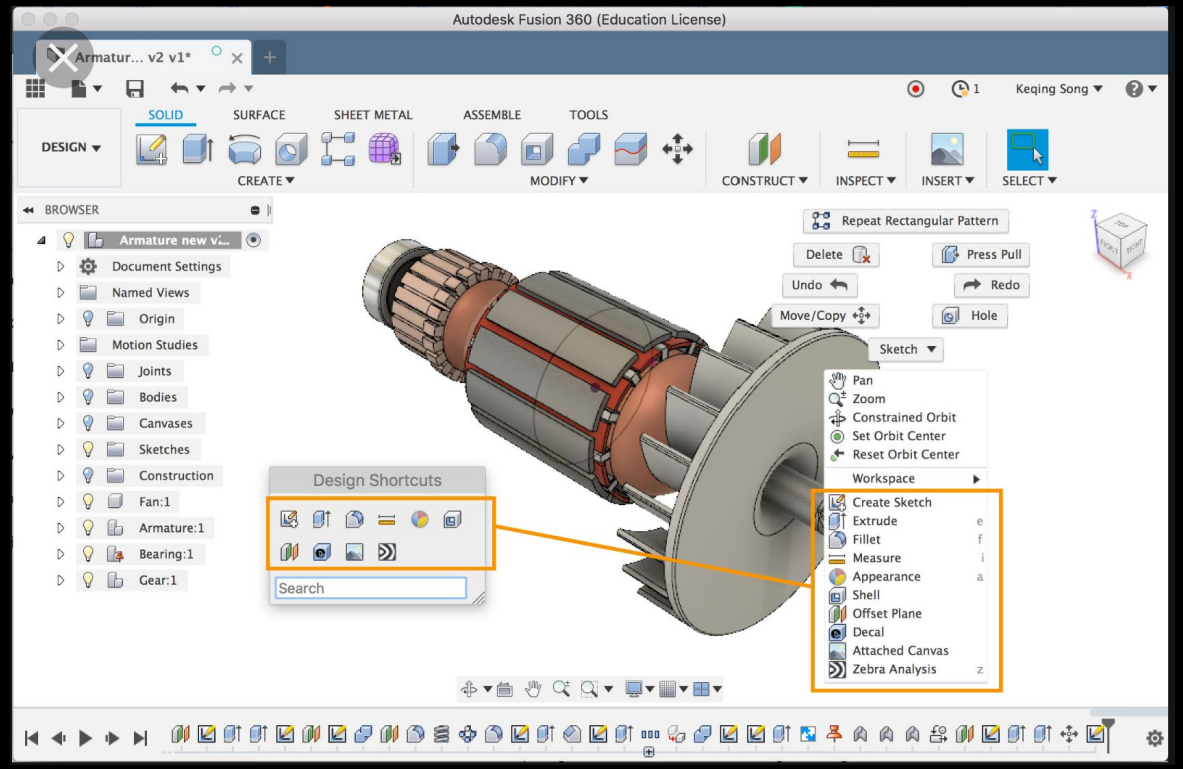


Development – Tools (Software)

- EasyEDA – Schematic & PCB Design for Manufacturing



- AutoDesk Fusion 360 – CAD Design for Board Layout Planning & 3D Printed Enclosure



Source:
https://www.google.com/search?q=fusion+360+images&rlz=1C1JZAP_enUS836US837&tbm=isch&source=iu&ictx=1&fir=_mdYx_vx_9qjiM%253A%252C6rRNoQFv-i1dVM%252C_&vet=1&usg=AI4_-kSW7pLqBY_QAXRN8cKCO9IK3v9p0g&sa=X&ved=2ahUKEwj9s9yk9qvkAhUKPa0KHYXWBsAQ9QEwAXoECAUQCQ#imgrc=RJdmrm7LvTjwyM:&vet=1

Development – Tools (Software)

- Arduino IDE – C++ Development Environment used for ESP32 firmware

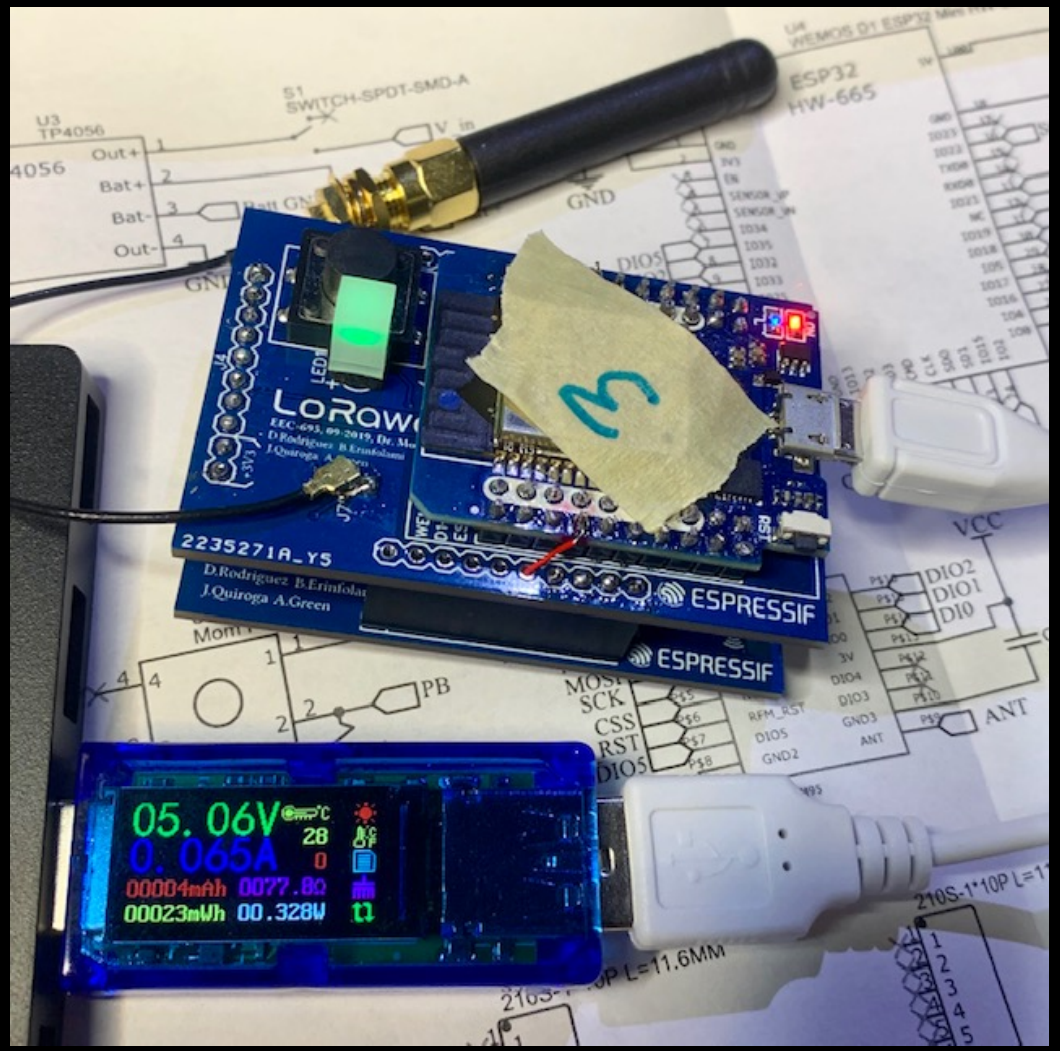
LW_Device1_V6 §

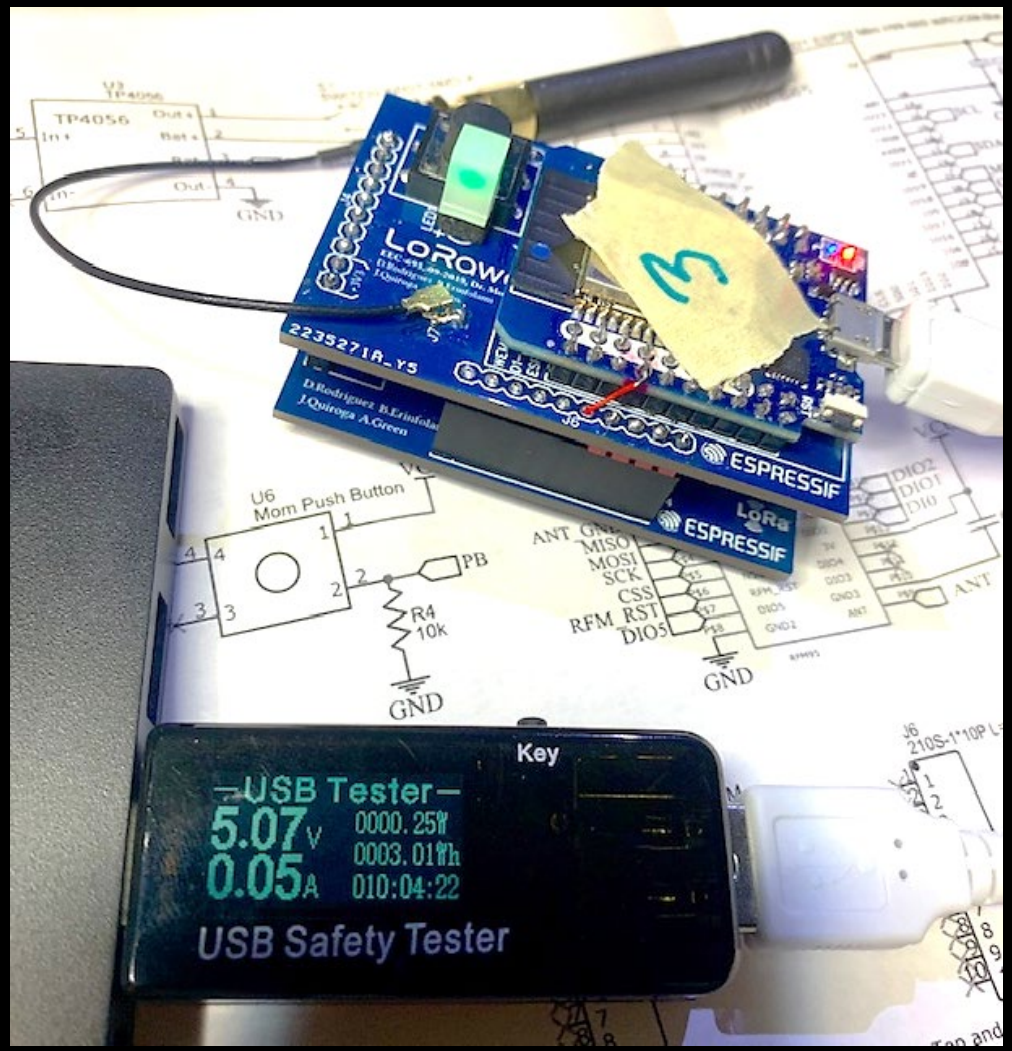
```
70
71 void LEDbreathe() {
72   for (int i = 0; i < 360; i++) {
73     analogWrite(readLED, (sin(i * 0.0174533) + 1) * (127/16));
74     delay(6);
75 }
76
77 void LoRaware_norm() {
78   LEDbreathe();
79   particleSensor.wakeUp();
80   bufferLength = 100; //buffer length of 100 stores 4 seconds of samples running at 25sps
81   //reads the first 100 samples, and determine the signal range
82   for (byte i = 0 ; i < bufferLength ; i++)
83   {
84     while (particleSensor.available() == false) //do we have new data?
85       particleSensor.check(); //Check the sensor for new data
86
87     if (eState == true) {
88       break;
89     }
90     else {
91      redBuffer[i] = particleSensor.getRed();
92      irBuffer[i] = particleSensor.getIR();
93      particleSensor.nextSample(); //We're finished with this sample so move to next sample
94     }
95   }
96   //calculate heart rate and SpO2 after first 100 samples (first 4 seconds of samples)
97     maxim_heart_rate_and_oxygen_saturation(irBuffer, bufferLength, redBuffer, &spo2, &validSPO
98   float measuredvbat = analogRead(battPin);
99   float battV;
100  battV = (((measuredvbat)*(2.1) / (4096)))*2;
101  dtostrf(battV,6, 3, myStrVB);
102  dtostrf((bme.readTemperature()*(1.8) + 32),6, 3, myStrT);
103  dtostrf(bme.readHumidity(),6, 3, myStrH);
104  dtostrf(heartRate,6, 2, myStrHR);
105  dtostrf(spo2,6, 2, myStrO2);
106    String str;
107    str = (String(myStrVB) +","+ String(myStrT) +","+ String(myStrH) +","+ String(myStrHR) +",
108    unsigned int str_len = 37;
109    str.toCharArray(payload,str_len);
110    Serial.println(payload);
111  // LoRaWAN Data Send Uplink to Gateway
112    lora.sendUplink(payload, strlen(payload), 0); // 0 = UNCONFIRMED Message
113    analogWrite(readLED,0);
114    particleSensor.shutDown();
115    delay(5000);
```

System Testing

- Proof-of-Concept Testing
  - Breadboard circuitry
  - Transducer Operation
  - RF Transmissions
  - Packet Management
  - Data Display
- Prototype Testing - Static and Dynamic
  - Power Usage Measurement and Battery Life Calculations
    - Comparison against 16 hour Battery Life Benchmark
  - Single (wired/wireless) and multi-node data captures (wireless)
    - Comparison against benchmark values
    - “calibrated” sensors – Fingertip Oximeter/HR, Laser Temperature Gun

Development – Power Usage





Power Usage Testing Results

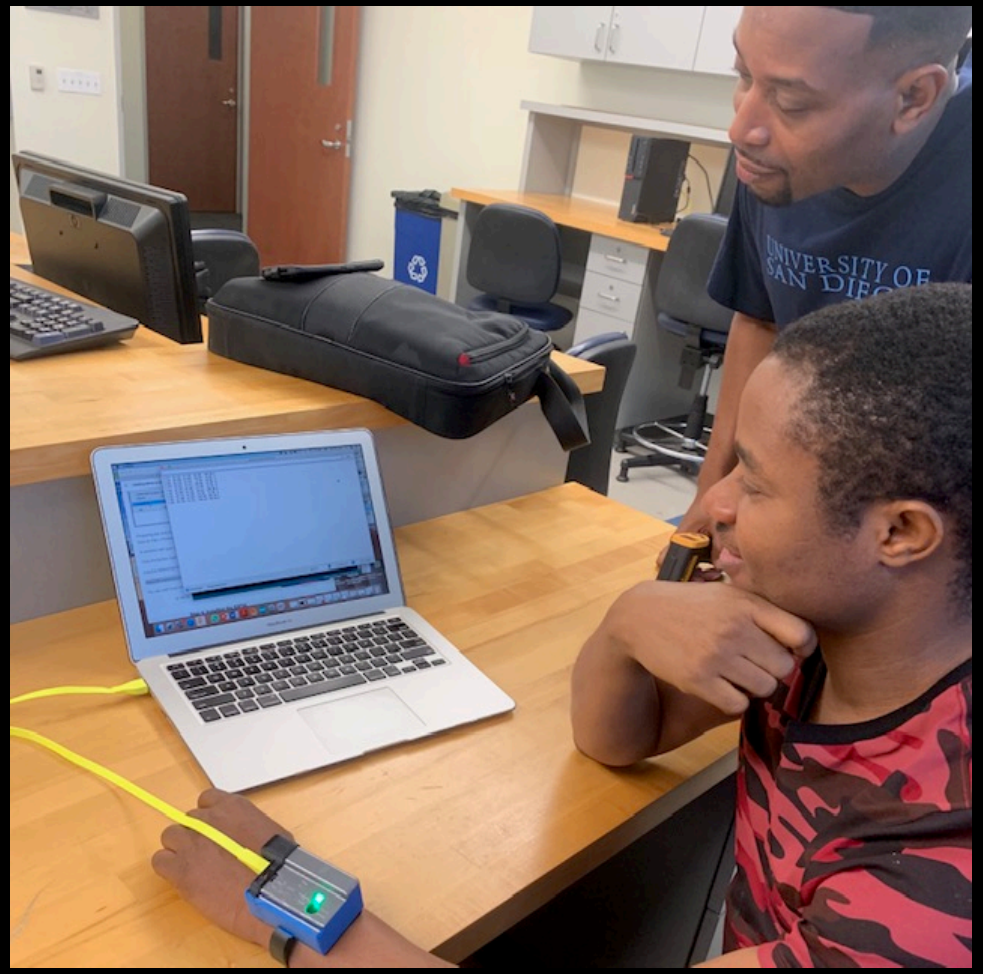
Li-Po Battery Capacity (mAh):	2000
Target Battery Life (hrs.):	16

USB Power Meter 1 (Blue)			
Device	**Current Draw (mA)**	**Power (W)**	**Battery Life (hrs.)**
LoRaware_1	66.0	0.333	30.30
LoRaware_2	63.0	0.319	31.75
LoRaware_3	60.0	0.303	33.33
LoRaware_4	58.0	0.298	34.48
Average Battery Life (hrs.):			32.47
Average Percent Improvement (%):			102.91

USB Power Meter 2 (Black)			
Device	**Current Draw (mA)**	**Power (W)**	**Battery Life (hrs.)**
LoRaware_1	50.0	0.253	40.0
LoRaware_2	50.0	0.253	40.0
LoRaware_3	50.0	0.253	40.0
LoRaware_4	40.0	0.202	50.0
Average Battery Life (hrs.):			42.5
Average Percent Improvement (%):			165.6

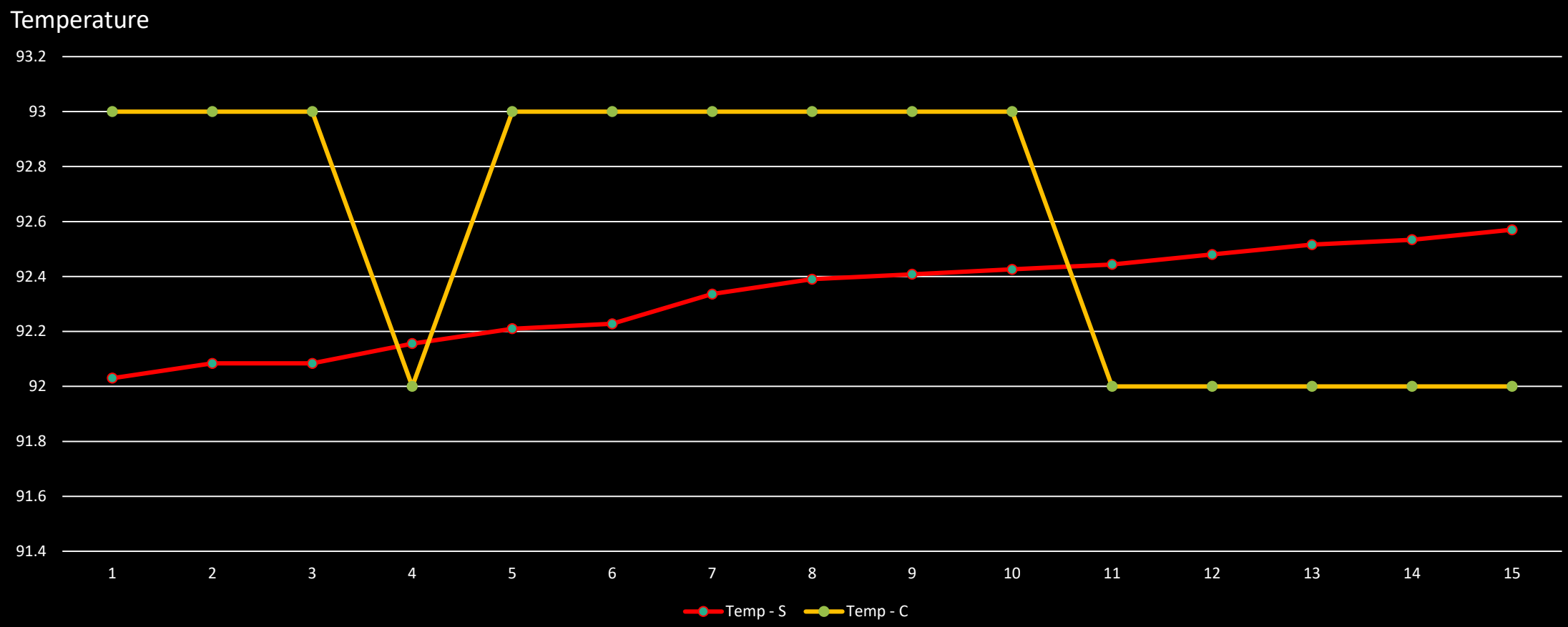
Overall Average Battery Life (hrs.)	37.48
Overall Average Percent Improvement (%)	134.27

Testing – Sensor Data Captures



Static Testing – Temperature Sensor (S) vs Calibrated (C)

Averages	
Calibrated	92.6^0 F
Sensor	92.3^0 F

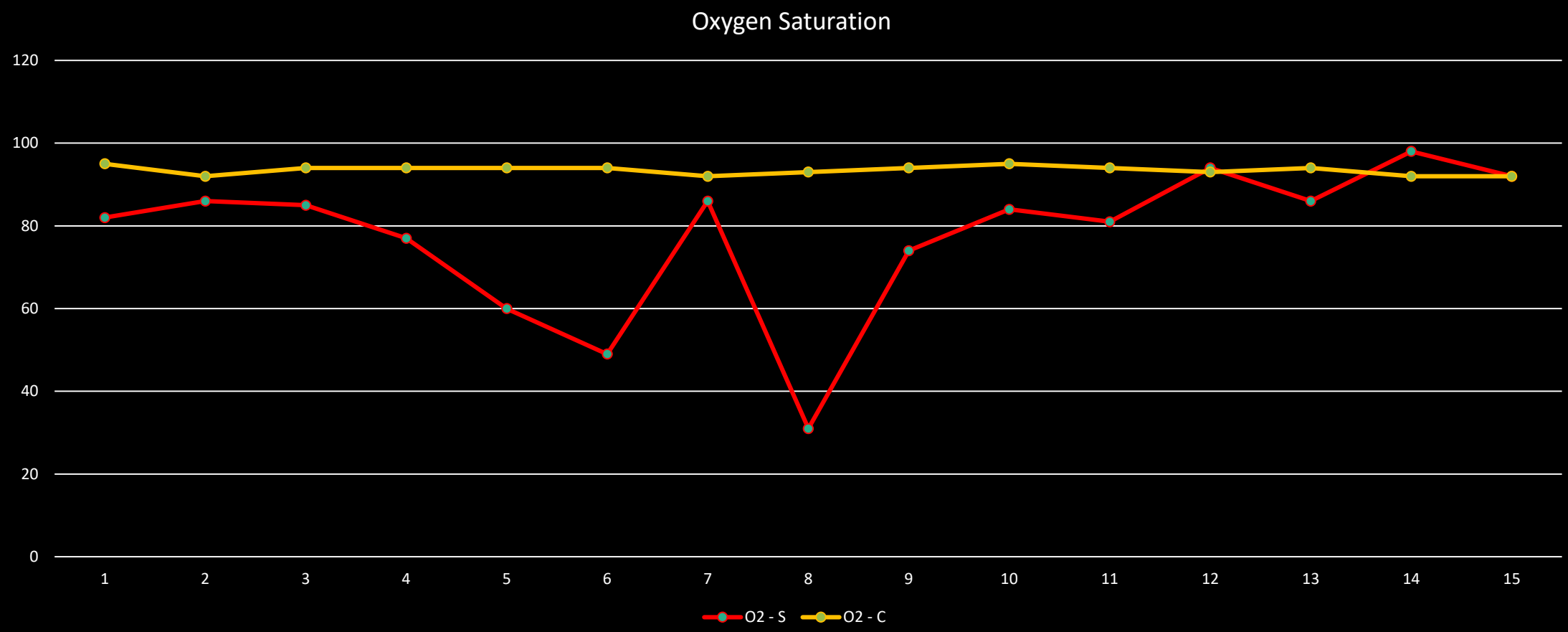


Static Testing – Heart Rate Sensor (S) vs Calibrated (C)

Averages	
Calibrated	120.7 BPM
Sensor	72.7 BPM

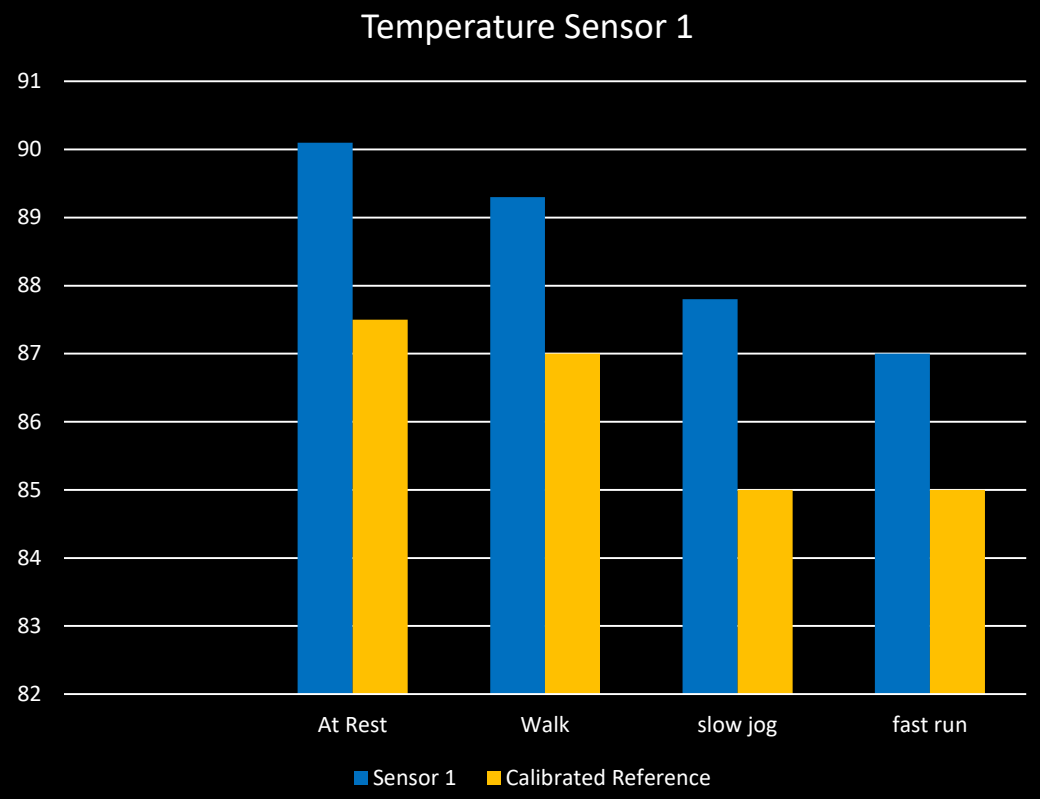
Static Testing – Oxygen Saturation Sensor (S) vs Calibrated (C)

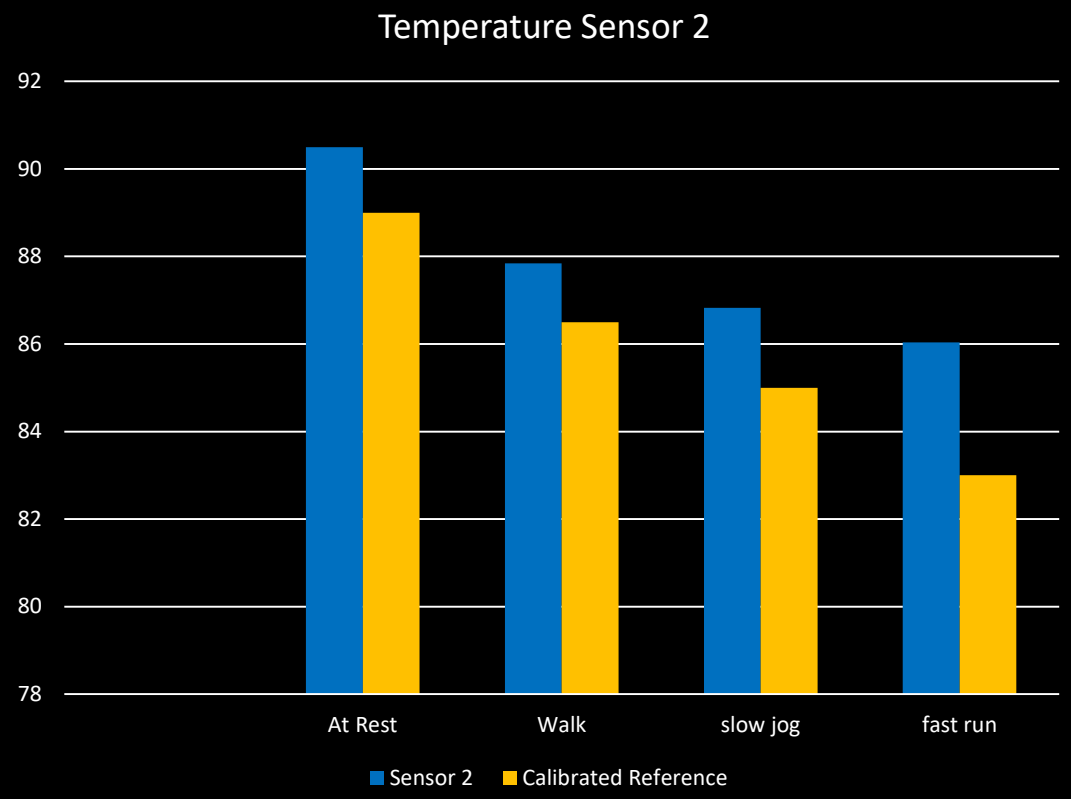
Averages	
Calibrated	93.5 %
Sensor	77.6 %



Dynamic Testing – Temperature

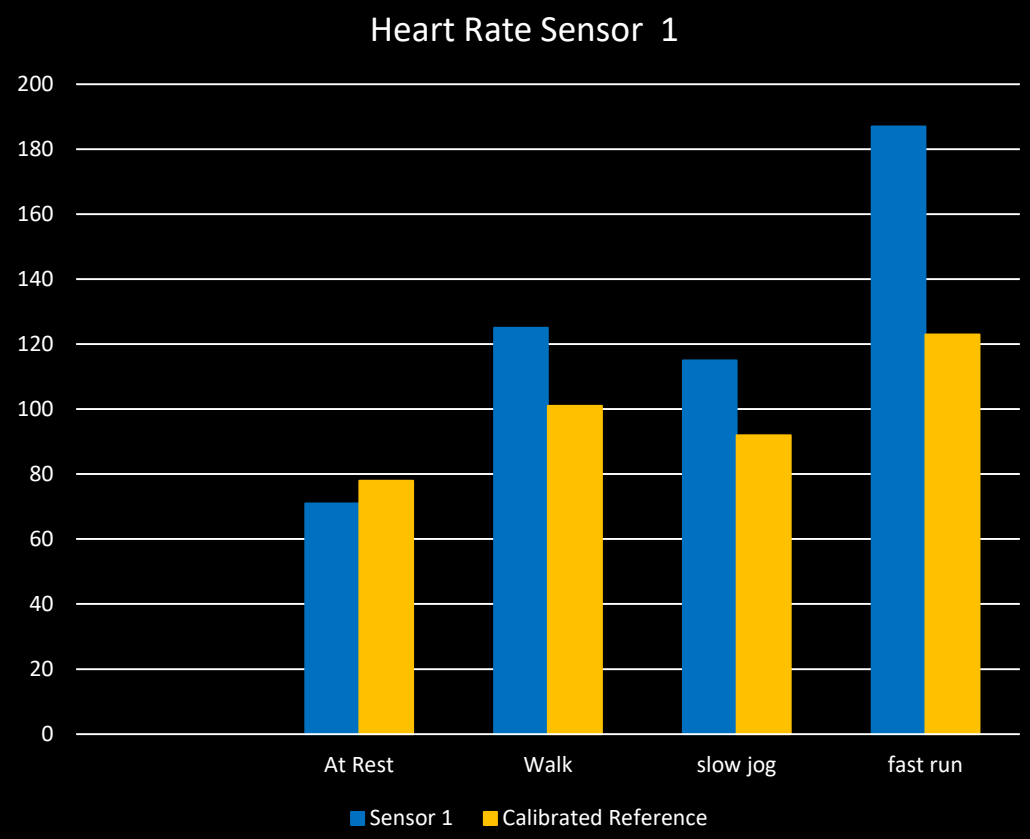
Average Difference	
Sensor 1	2.42^0 F
Sensor 2	1.92^0 F

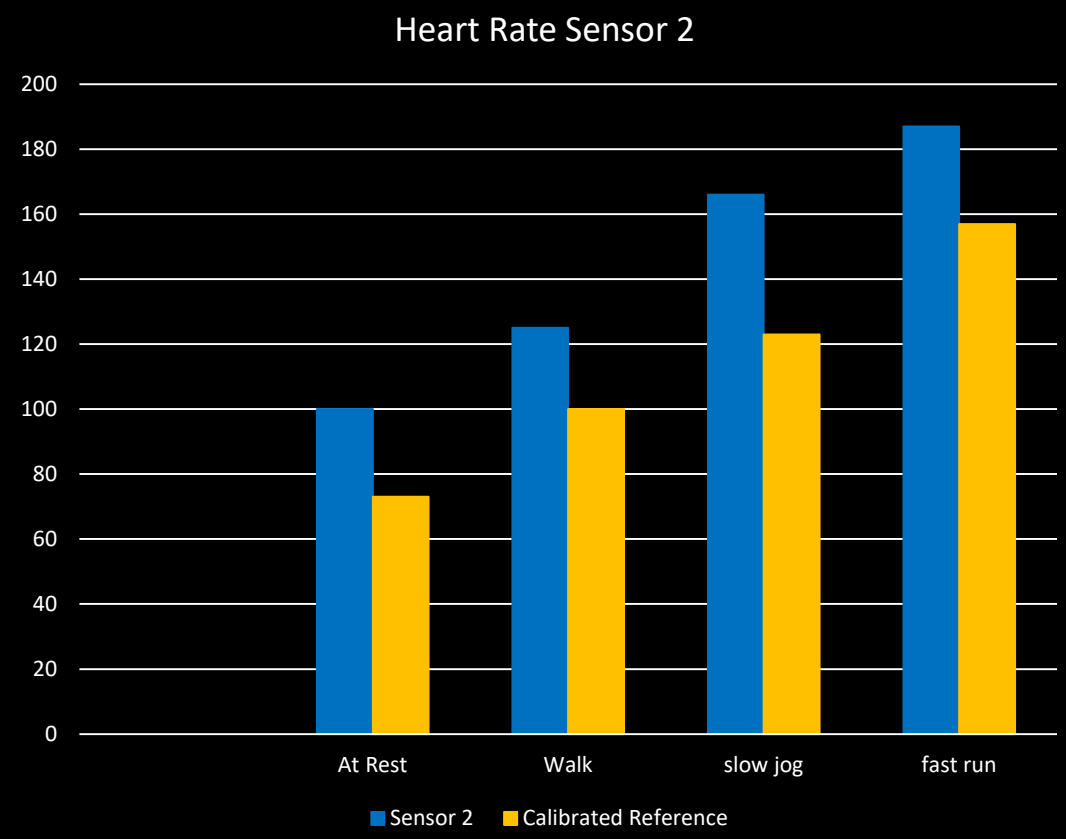




Dynamic Testing – Heart Rate

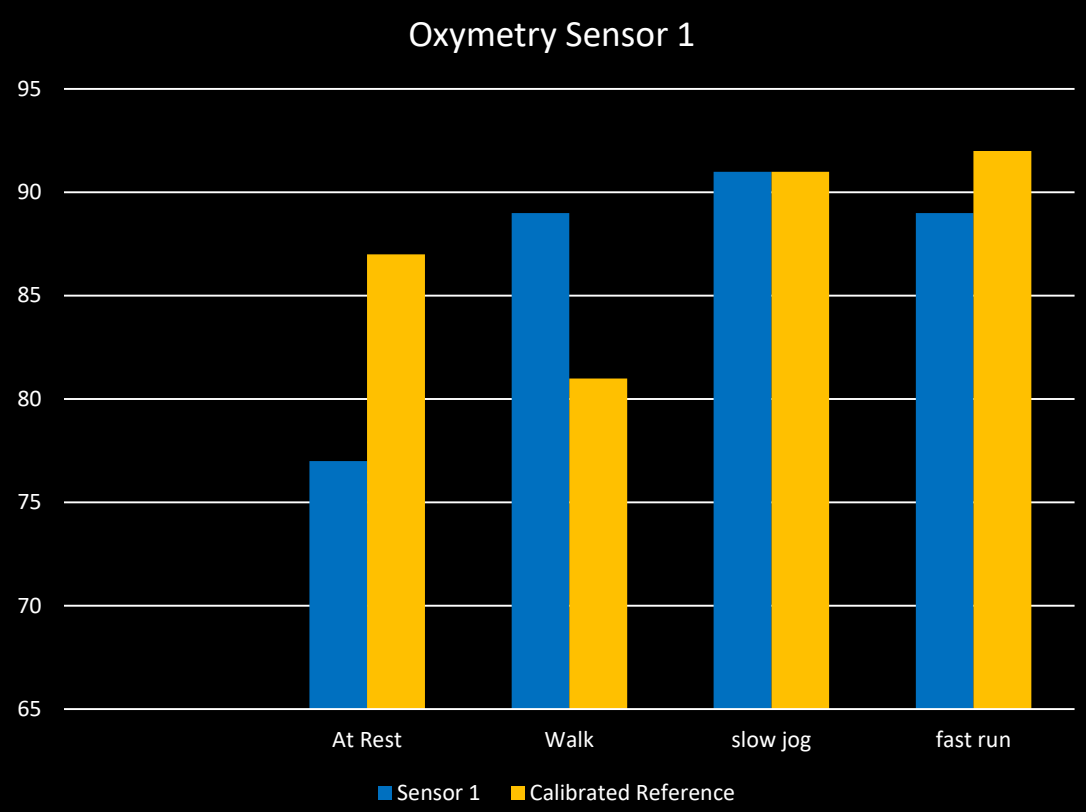
Average Difference	
Sensor 1	26 BPM
Sensor 2	31 BPM

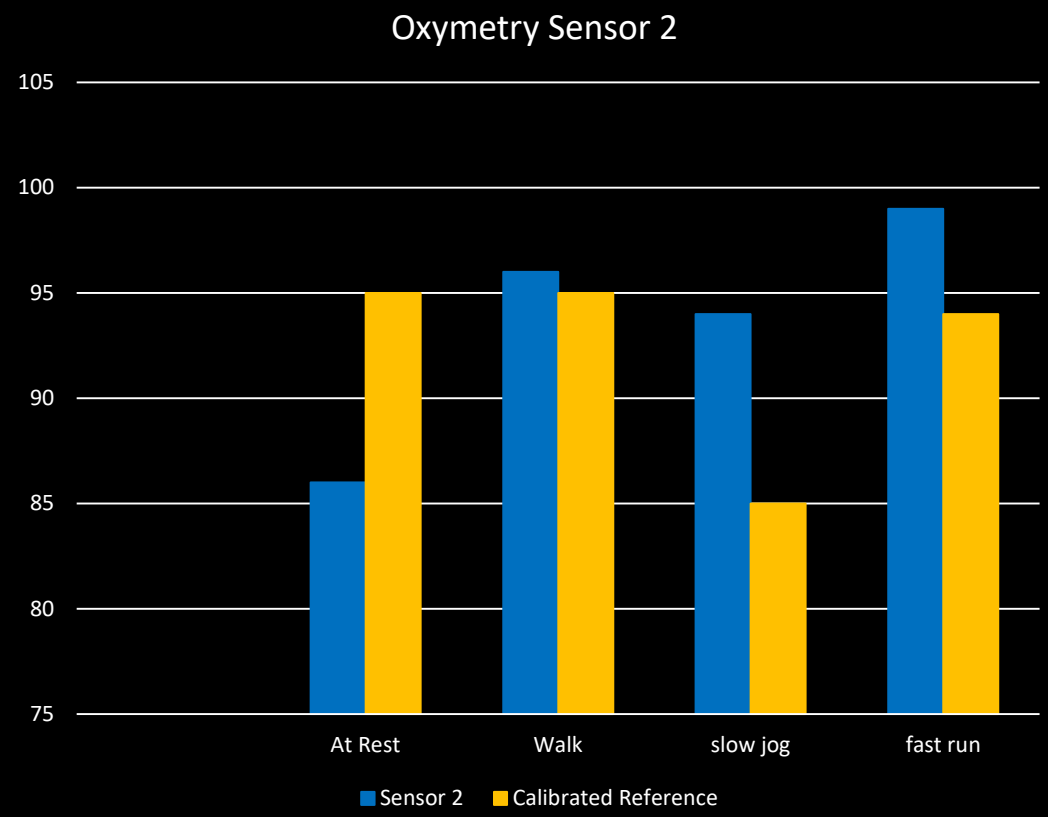




Dynamic Testing – Oxygen Saturation

Average Difference	
Sensor 1	1.25 %
Sensor 2	1.50 %





Testing - Summary

- Additional Sensor Calibration is crucial for future development

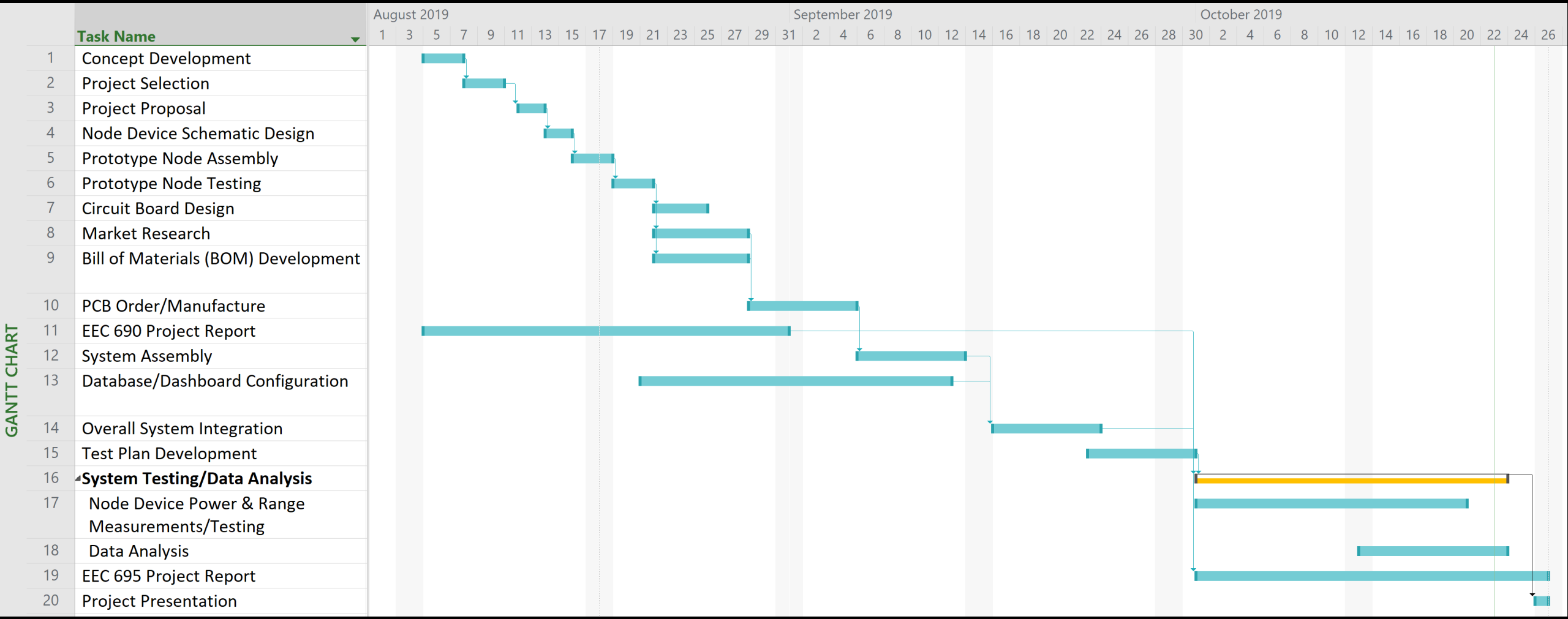
- LoRaware Device performance in Power Usage was able to surpass our projected benchmark value

Project Management – Cost

- Handling of resources to attain intended goals:
  - Cost - Labor/Material resources
  - Schedule -Time
  - Performance – Working product

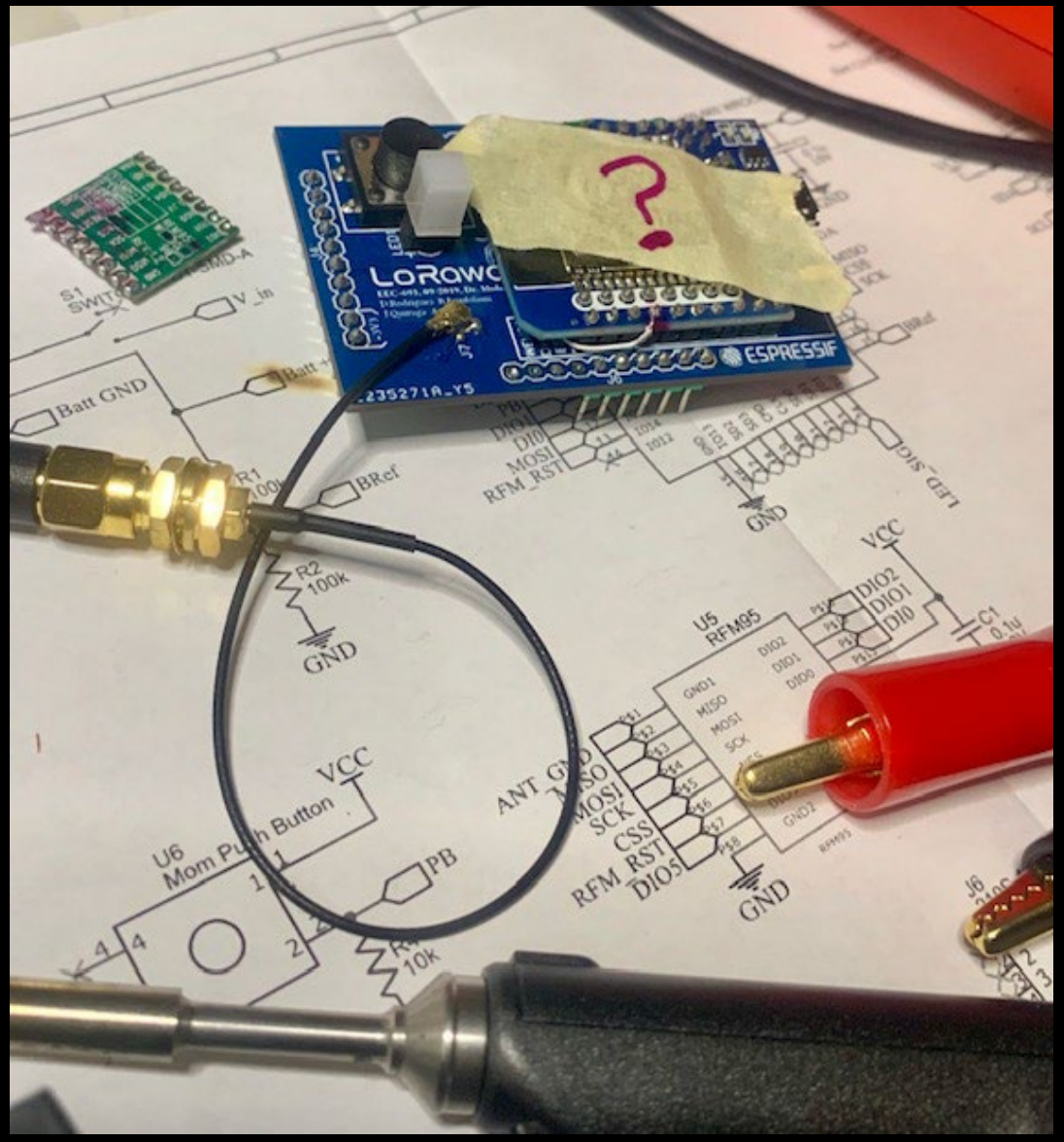
MATERIALS	Unit Cost	# Units	Total Cost
MatchX LoRa Gateway	$ 450.00	1	$ 450.00
RFM95 LoRa Module	$ 20.00	4	$ 80.00
TP4056 Li-Ion Charge Protection IC	$ 1.20	4	$ 4.80
2000 mAh Lithium Polymer Battery	$ 10.00	4	$ 40.00
ESP32 – Microcontroller	$ 10.00	4	$ 40.00
MAX30102 HRT/O2LT Sensor	$ 8.00	4	$ 32.00
BME208 Temperature/Pressure Sensor	$ 2.00	4	$ 8.00
Raspberry Pi 3B+	$ 30.00	1	$ 30.00
LoRa 915 MHz Antenna	$ 10.00	4	$ 8.00
IPX ULF Connector	$ 0.60	4	$ 2.40
PCB’s manufactured by JLC PCB	$ 2.00	5	$ 10.00
TOTAL MATERIAL			**$ 705.20**

Project Management – Schedule



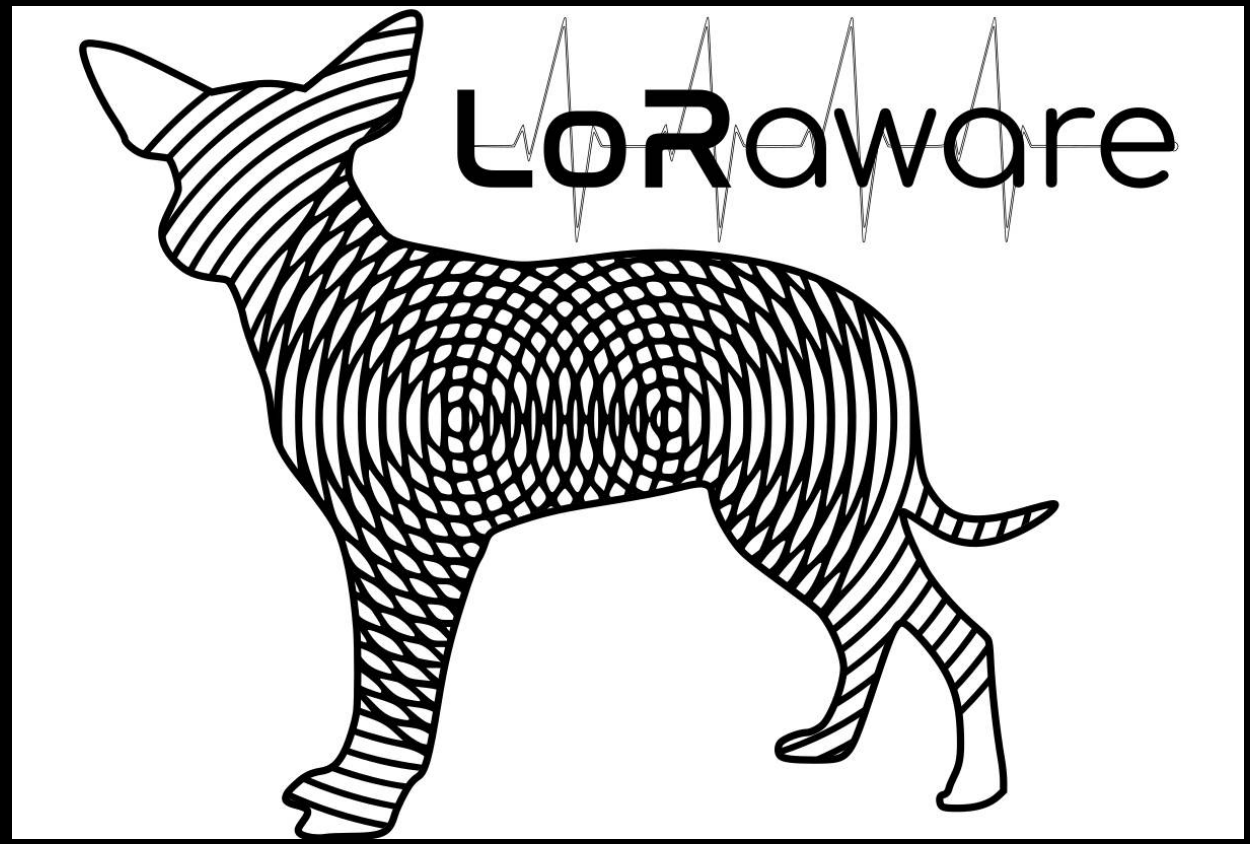
Future Capabilities & Continued Research

- Cloud Integration / Web Deployment
- ESP32 Power Saving Sleep Modes (Light Sleep & Deep Sleep)
- Dynamic Wireless Protocol Hybridization (Wi-Fi, Bluetooth 4.0, LoRa)



Closing Points & Demo

- Team Achieved Objectives
  - Successfully Tested Design
    - Systematic Approach
    - Applied Knowledge Gained
    - Proved Concept Works
    - Added ESP32 Compatibility to Arduino LoRaWAN Library
    - Demonstrated Significant Power Usage Improvements over competitor product
  - Design can be Further Developed
  - Used Available Resources at Minimal Cost
    - Showcased Free Software Tools for Future Academic utilization



References

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- https://www.amazon.com/gp/product/B07TGJTCTB/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1
- https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32d_esp32-wroom-32u_datasheet_en.pdf
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- https://easyeda.com
- https://www.labnol.org/tech/types-of-wireless-networks/13667/
- https://datasheets.maximintegrated.com/en/ds/MAX30102.pdf
- https://www.amazon.com/gp/product/B07GGSM8SP/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1
- https://www.mouser.com/new/bosch/bosch-bme280/?gclid=CjwKCAjwkqPrBRA3EiwAKdtwkyOZ-eQqDwHZ76aTq2MBWNVu5_Nky2wK5seoHWPx5W8nIIIyH63w6BoC_CkQAvD_BwE
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- https://blog.ampow.com/lipo-voltage-chart/
- https://www.amazon.com/gp/product/B07BTV4J26/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
- https://dlnmh9ip6v2uc.cloudfront.net/datasheets/Prototyping/TP4056.pdf
- https://www.amazon.com/gp/product/B01DRT4PWY/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
- https://www.labnol.org/tech/types-of-wireless-networks/13667/
- https://www.semtech.com/lora/what-is-lora
- https://www.link-labs.com/blog/sigfox-vs-lora
- https://www.matchx.io/product/matchx-gateway/
- https://nanotron.com/EN/CO_techn-css.php/
- https://www.maximintegrated.com/en/products/sensors/MAX30102.html/tb_tab0
- https://www.link-labs.com/blog/sigfox-vs-lora
- https://www.semtech.com/lora/what-is-lora
- https://www.soterawireless.com/why-visi/