Automated Heated Bridge System

Electrical & Computer Engineering

Team Members: Kahmil Hamzat, Adriel Taparra, James Raue
Group 52

5/5/2025

Objective

Problem

- Bridges freeze more quickly than regular roads
  - No Ground Insulation
  - Fully Exposed

Current Solutions

- Passive warning signs such as "Bridge Ices Before Road"
- Reactive and labor intensive solutions like salting and plowing

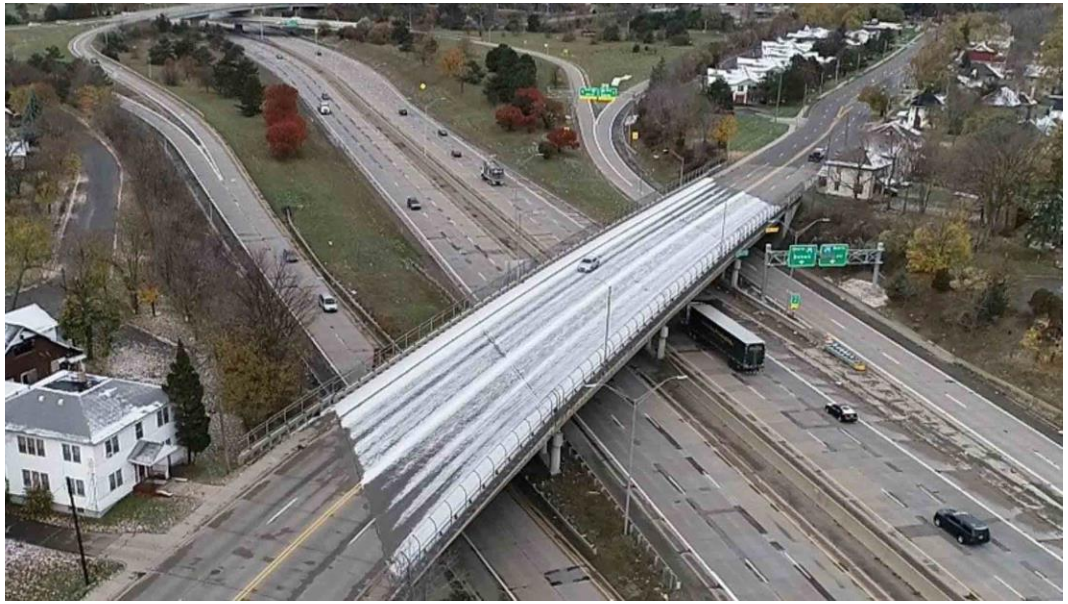
Objective

Solution

- Automatically prevent ice buildup on bridge surfaces to enhance safety.

System Goal

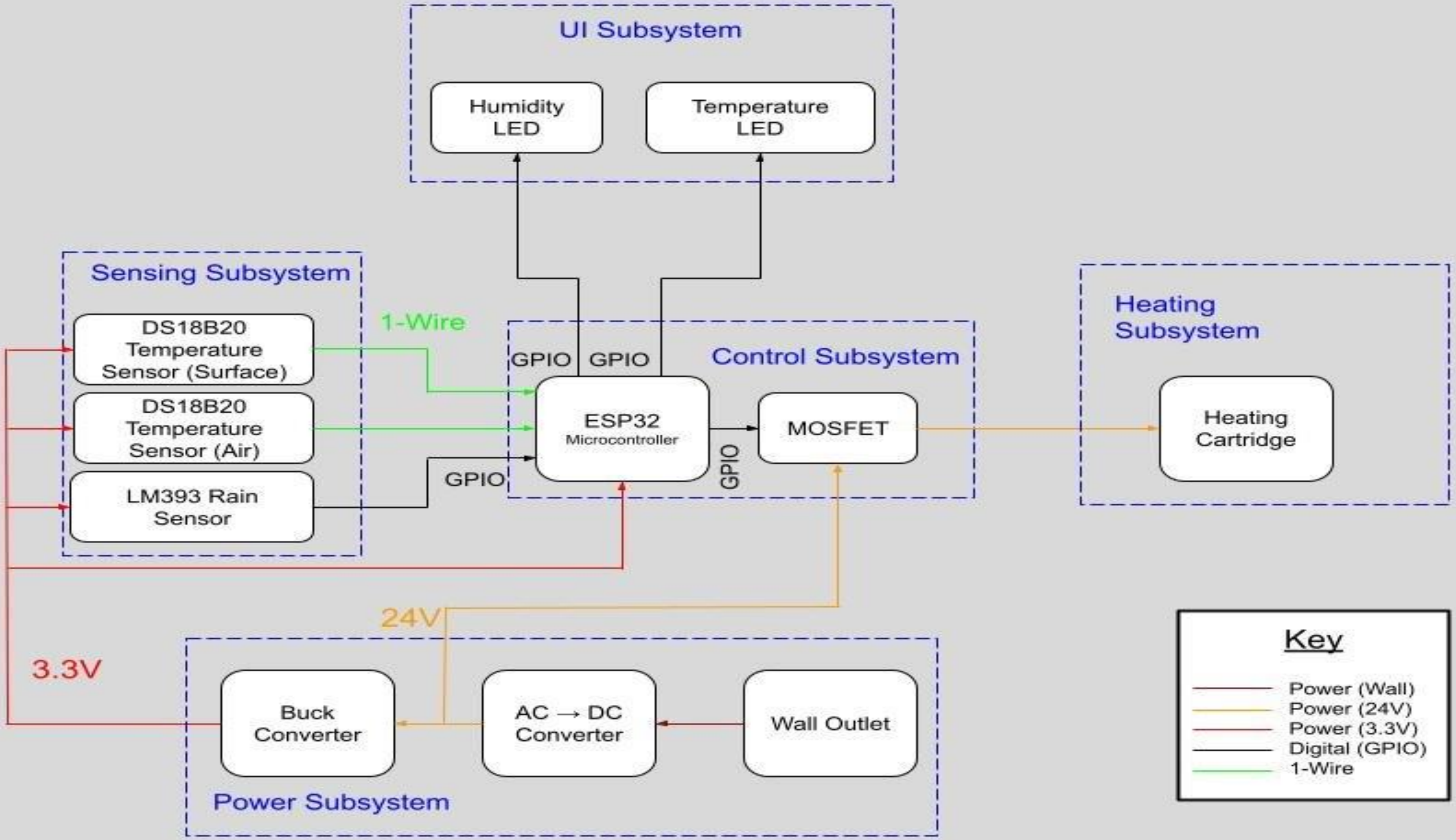
- Monitor environmental conditions and activate heating only when necessary to keep the bridge surface above freezing, reducing accident risk and energy waste.



High Level Requirements

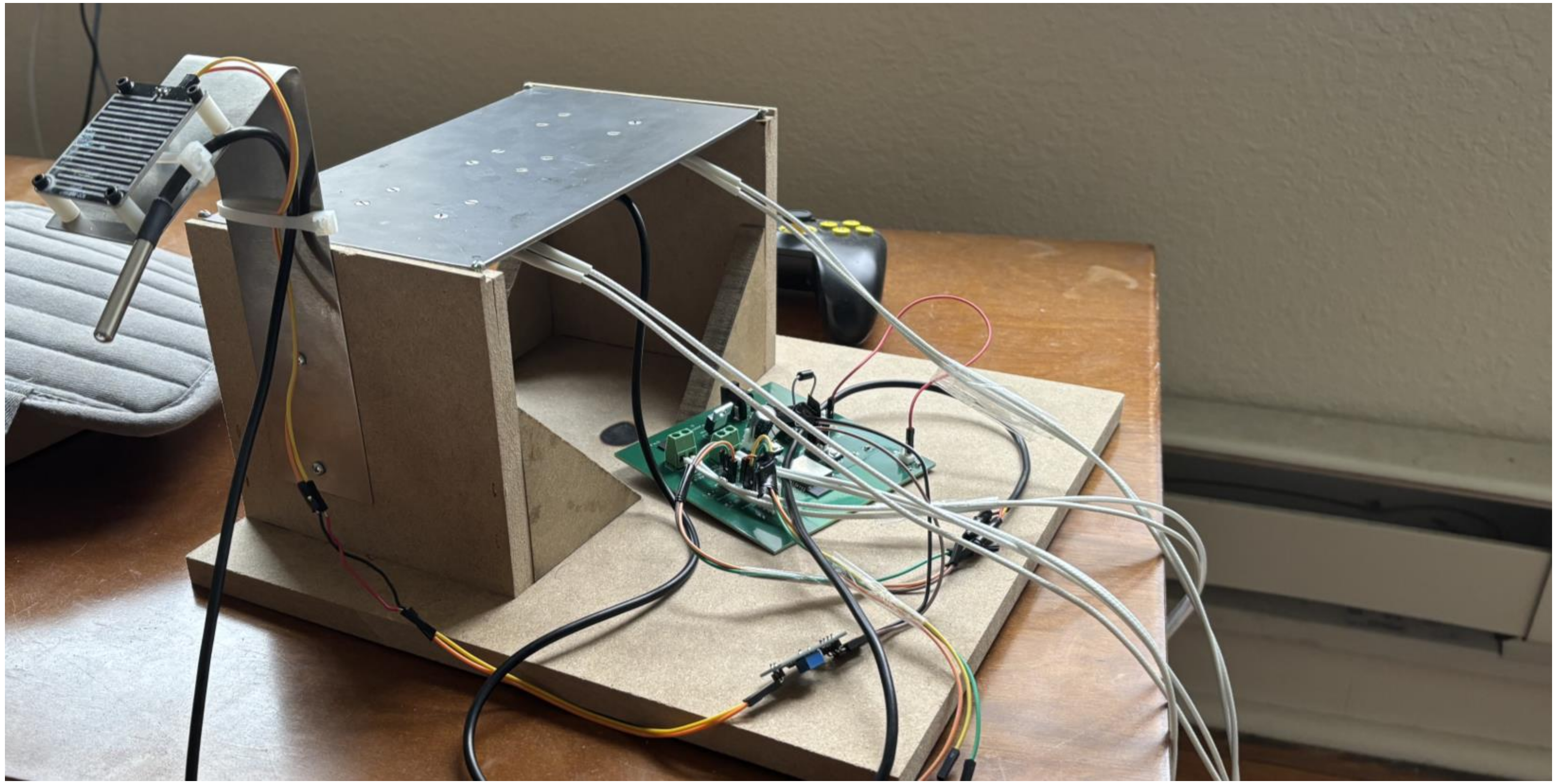
- **Accurate environmental sensing**
  - Detect surface temperature within ±1°C accuracy
  - Binary (wet/dry) moisture detection
- **Efficient heating capability**
  - Raise bridge surface temperature above 0°C
- **Automated power regulation**
  - Activate heating only when freezing temps & moisture are present
  - Automatically deactivate when conditions are safe

Design



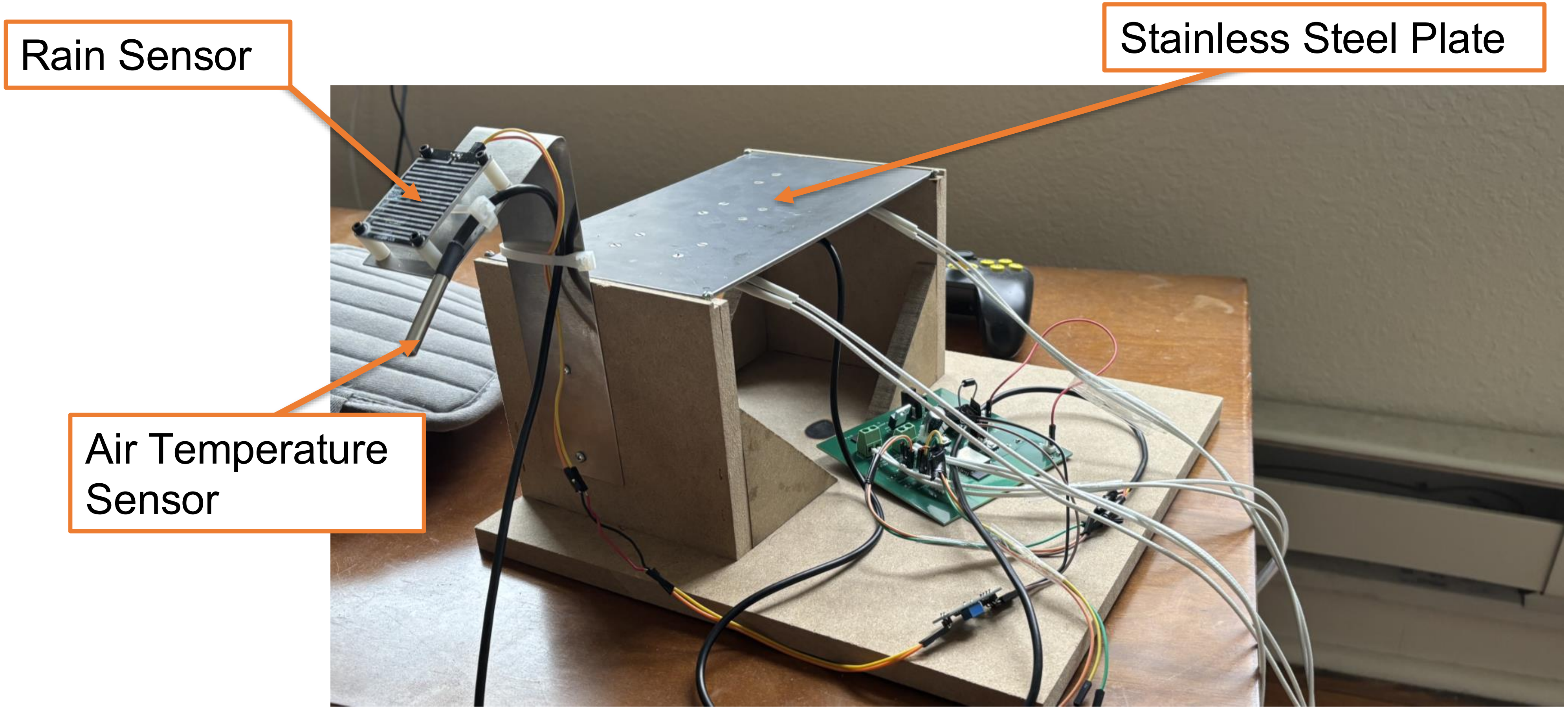
UI Subsystem
Humidity LED
Temperature LED
Sensing Subsystem
DS18B20 Temperature Sensor (Surface)
DS18B20 Temperature Sensor (Air)
LM393 Rain Sensor
1-Wire
GPIO
GPIO
GPIO
GPIO
Control Subsystem
ESP32 Microcontroller
MOSFET
Heating Subsystem
Heating Cartridge
24V
3.3V
Buck Converter
AC → DC Converter
Wall Outlet
Power Subsystem
Key
Power (Wall)
Power (24V)
Power (3.3V)
Digital (GPIO)
1-Wire

Testing Model for Heated Bridge



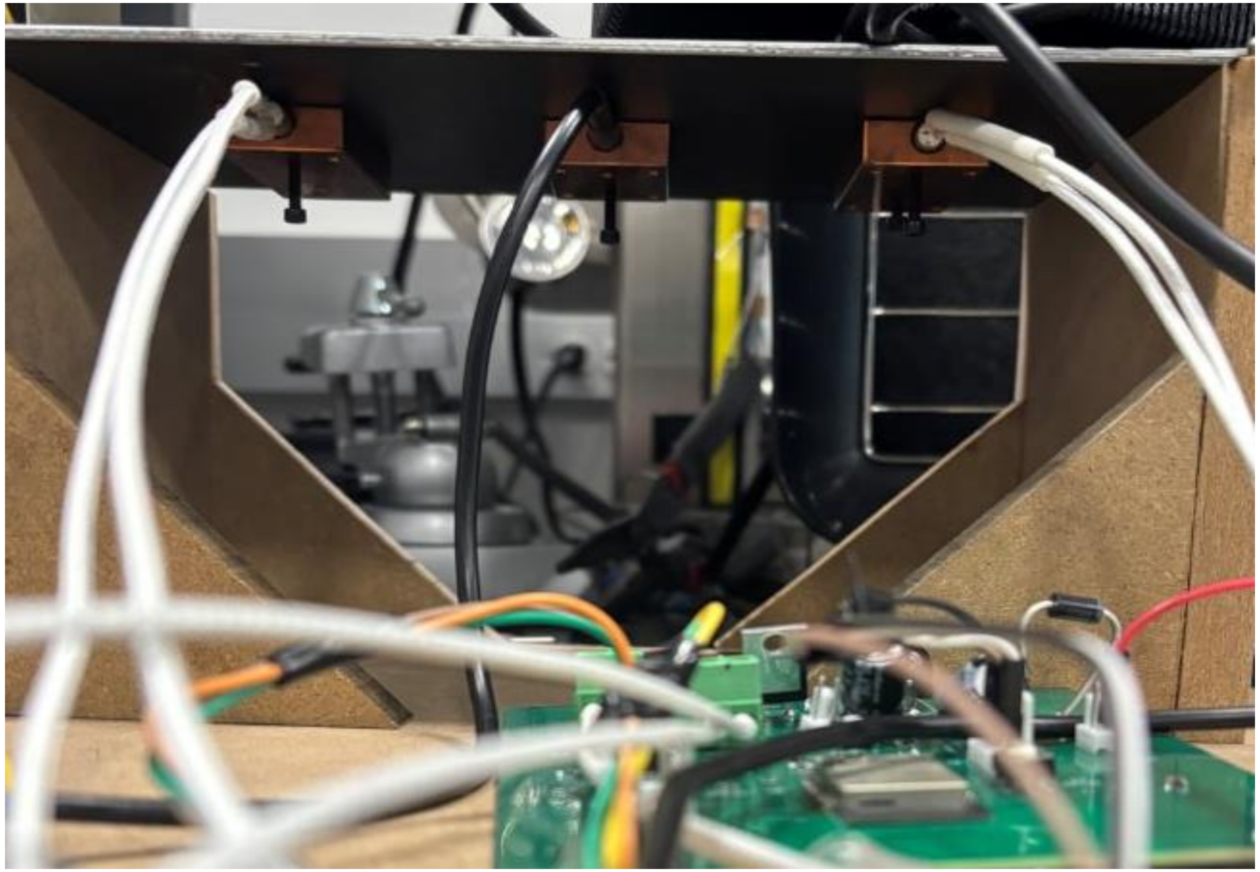
Test model for heated bridge system.

Testing Model for Heated Bridge



Test model for heated bridge system.

Bridge Model Underside



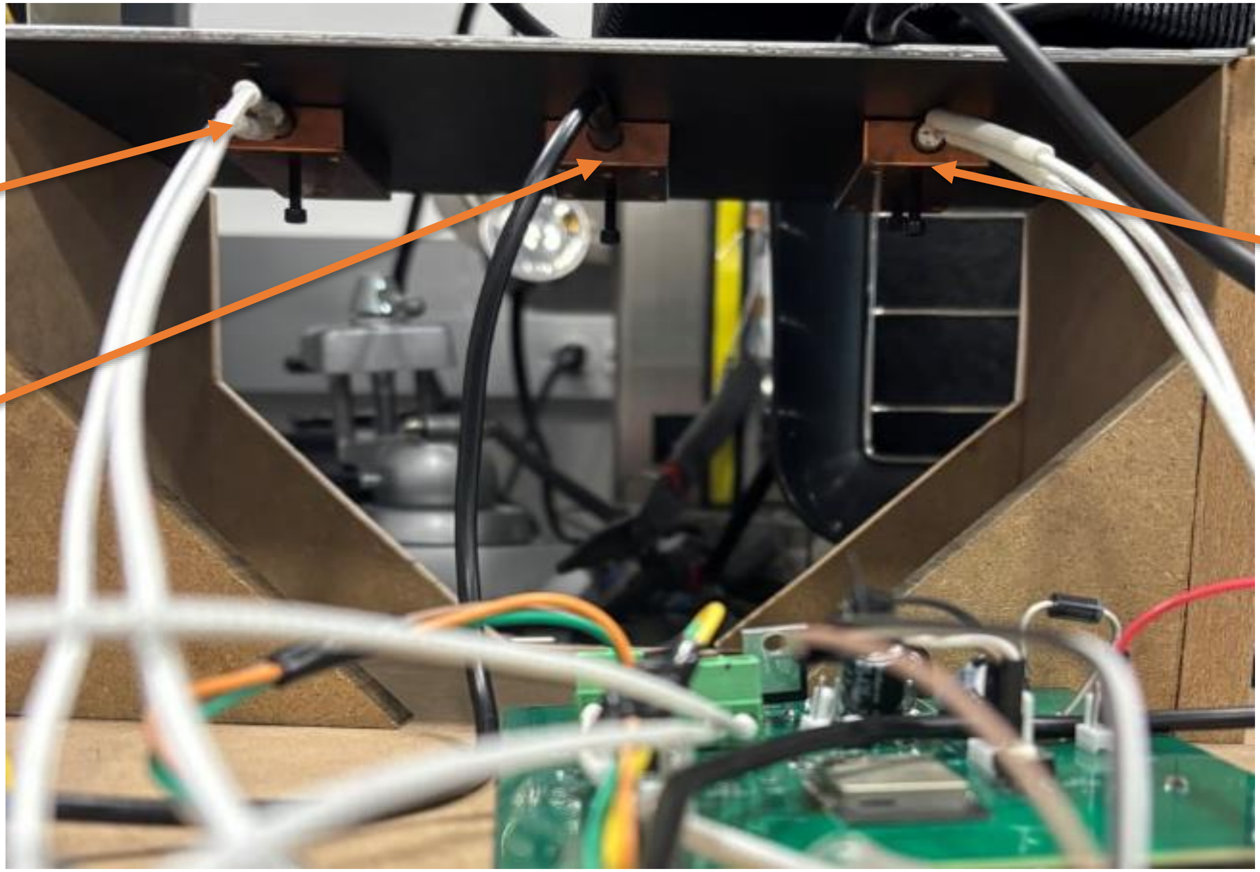
Underside of the bridge model

Bridge Model Underside

Heating Cartridge

Surface Temperature Sensor

Copper Holding Block

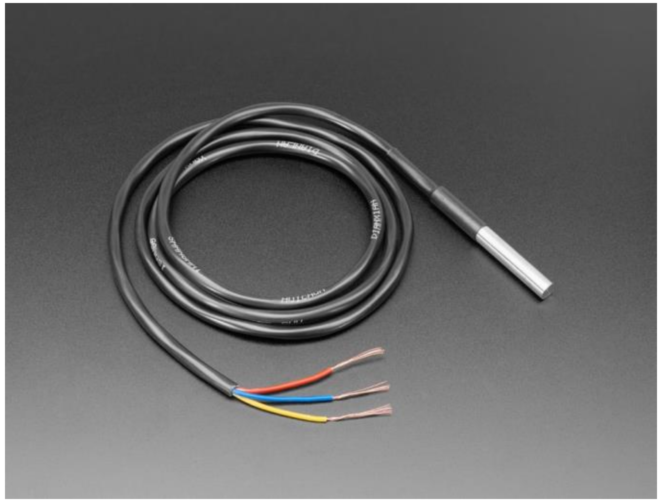


Underside of the bridge model

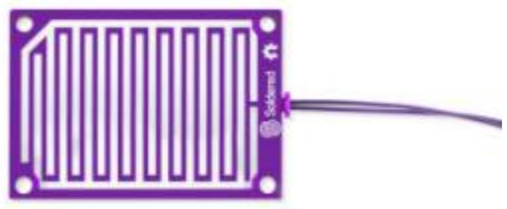
Subsystems

Sensing Subsystem

- DSB1820 Temperature Sensors
  - 3.3V Power
  - Supported library for reading temperature values
  - Measures temps from –55C to 125C with ±0.5 C Accuray between -10C to 85C
  - Waterproof



- 333044 Rain Sensor
  - 3.3V
  - Analog output – continuous values 0-4095 based on water level.



Control Subsystem

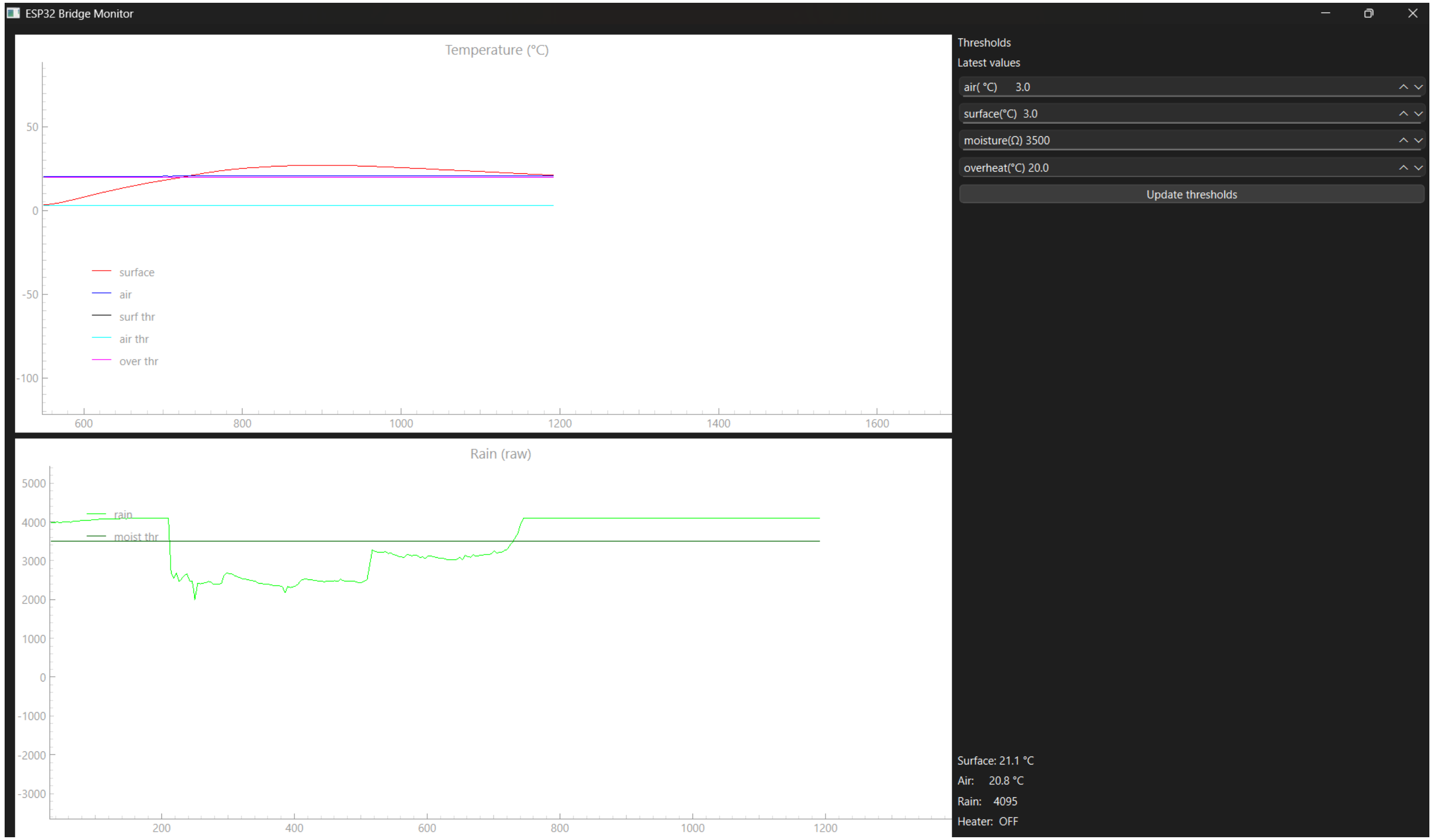
- ESP32-WROOM-32E-N4
  - Bluetooth capabilities for wireless monitoring and control
  - Multiple GPIO Pins and ADC Channels
- Functionality
  - Reads from Sensor Subsystem
  - Decides when to turn on heaters or turn them off using GPIO Output
  - Sends the sensor readings wirelessly through another device through Bluetooth
- Icy/Hazardous Conditions
  - Air Temperature or Surface Temperature goes below 3 degrees C
  - Moisture is detected

Subsystem

User Interface Subsystem

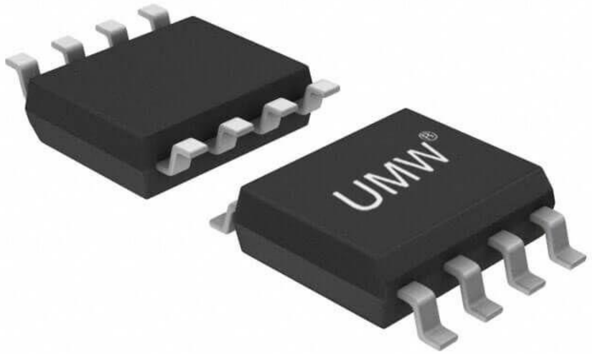
ESP-32 Built in BLE
- Transmits the current temperatures, rain value, and heater state.
- Receives updated thresholds from connected laptop.

Python Script
- QT Library to create the dashboard.
- Bleak Library to handle BLE communication.



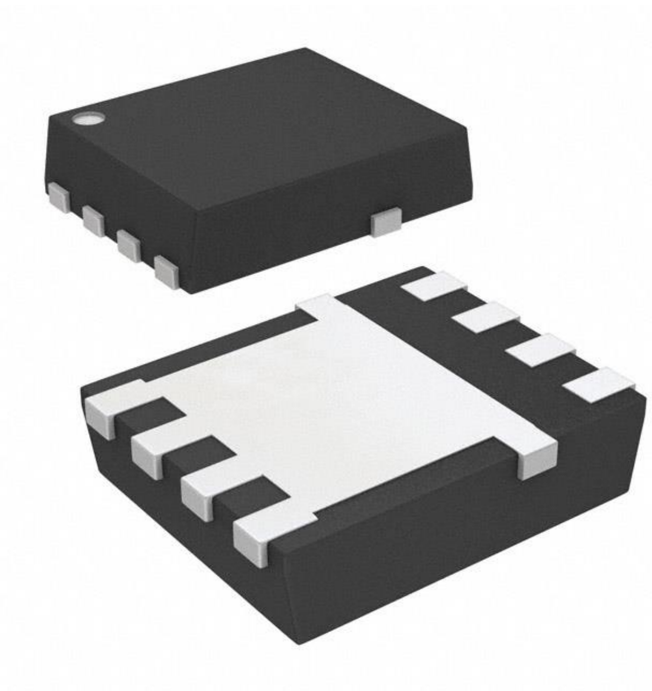
Power Subsystem

- AC-DC converter
  - 120V AC from wall outlet → 24V DC
  - Overcurrent protection
  - Temperature protection
- XL1509-3.3 Buck converter
  - 24V → 3.3V
  - Powers ESP32 and sensors
  - Constant 2A output
  - 4.5V to 40V input voltage range



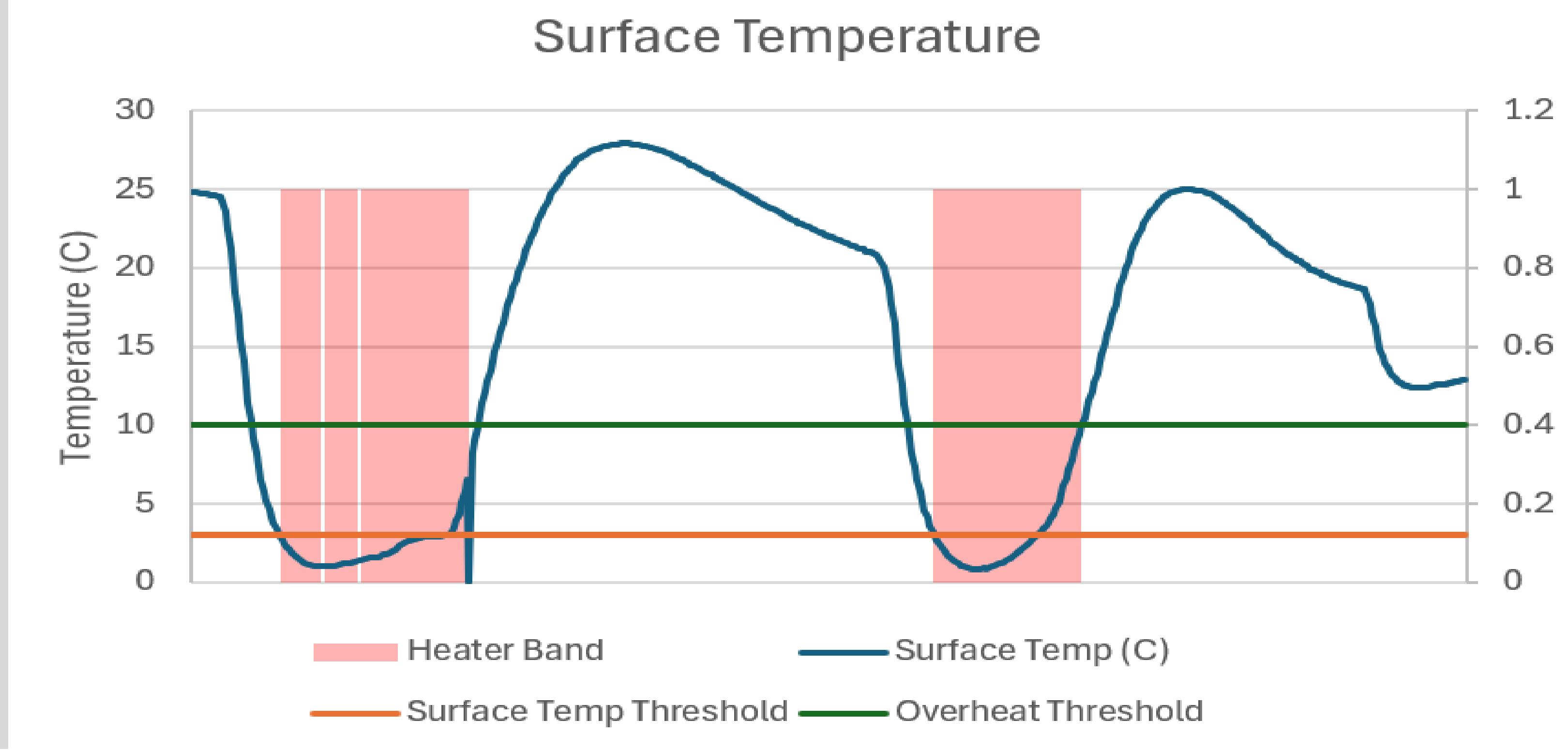
Heating Subsystem

- 2x Heater Cartridges
  - 24V, 70W each
  - Opposite ends of bridge surface
  - Under copper block
- CSD17312Q5 MOSFET
  - Allows current flow to heaters
  - Very low power dissipation
  - Low gate threshold (1.1V)
  - Rated for 30V, 38A



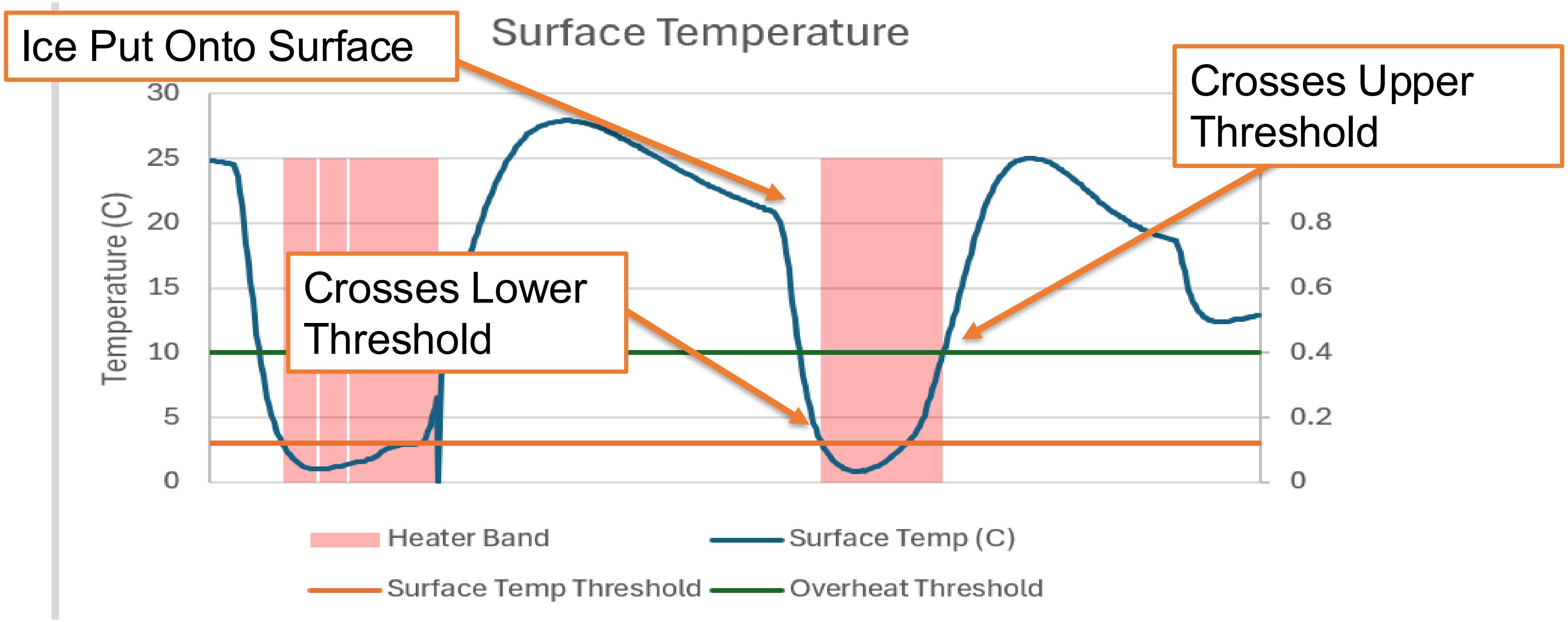
Test Results

Test Results (Surface Temperature)



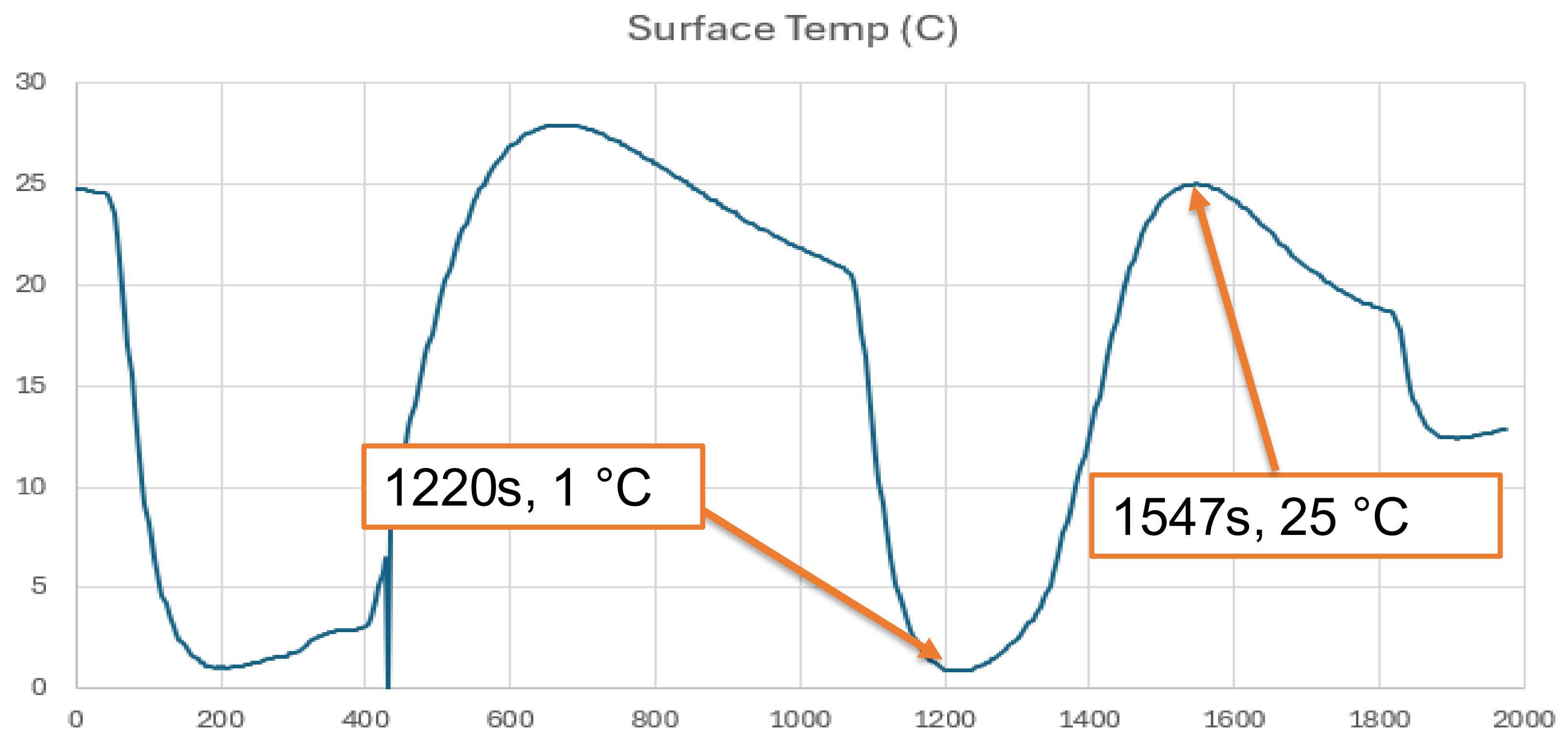
Graph of bridge surface temperature

Test Results (Surface Temperature)



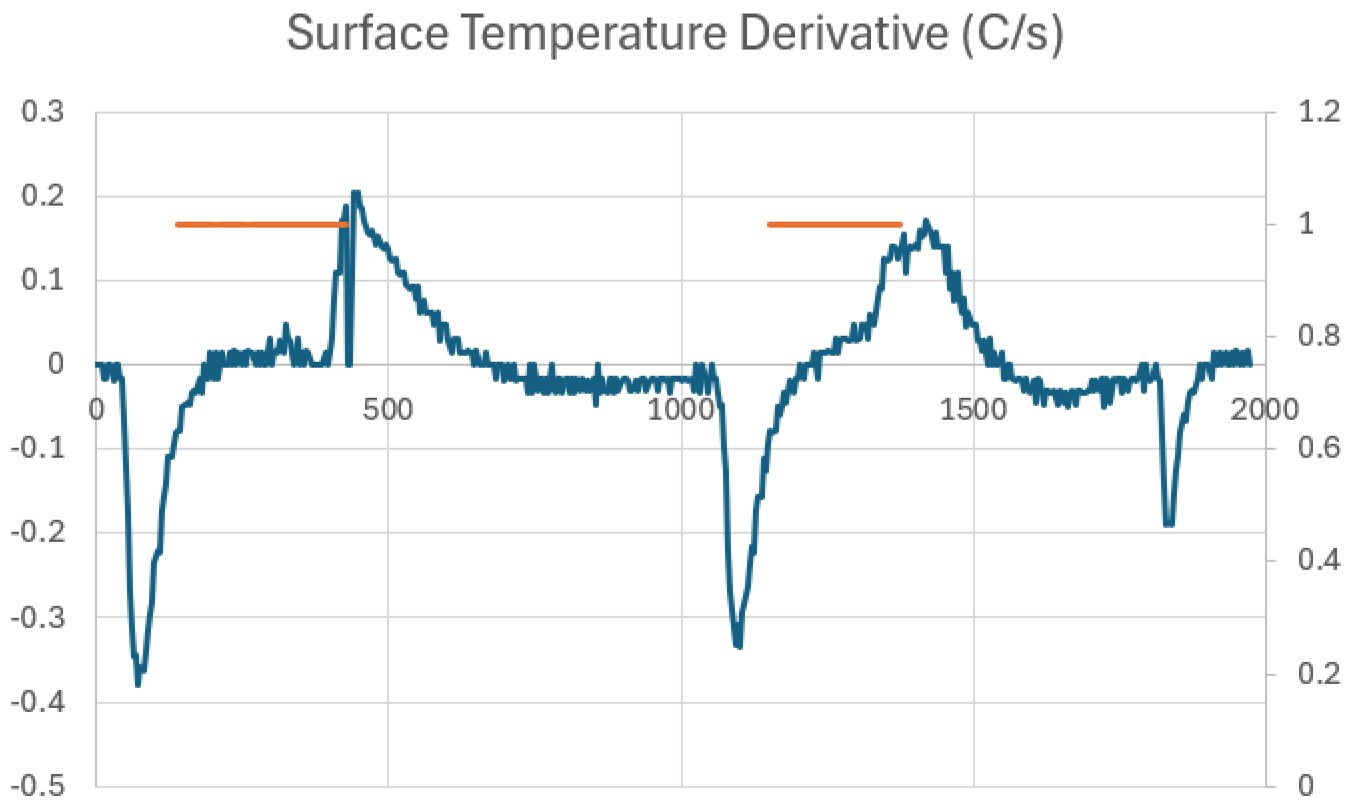
Graph of bridge surface temperature

Test Results (Surface Temperature)



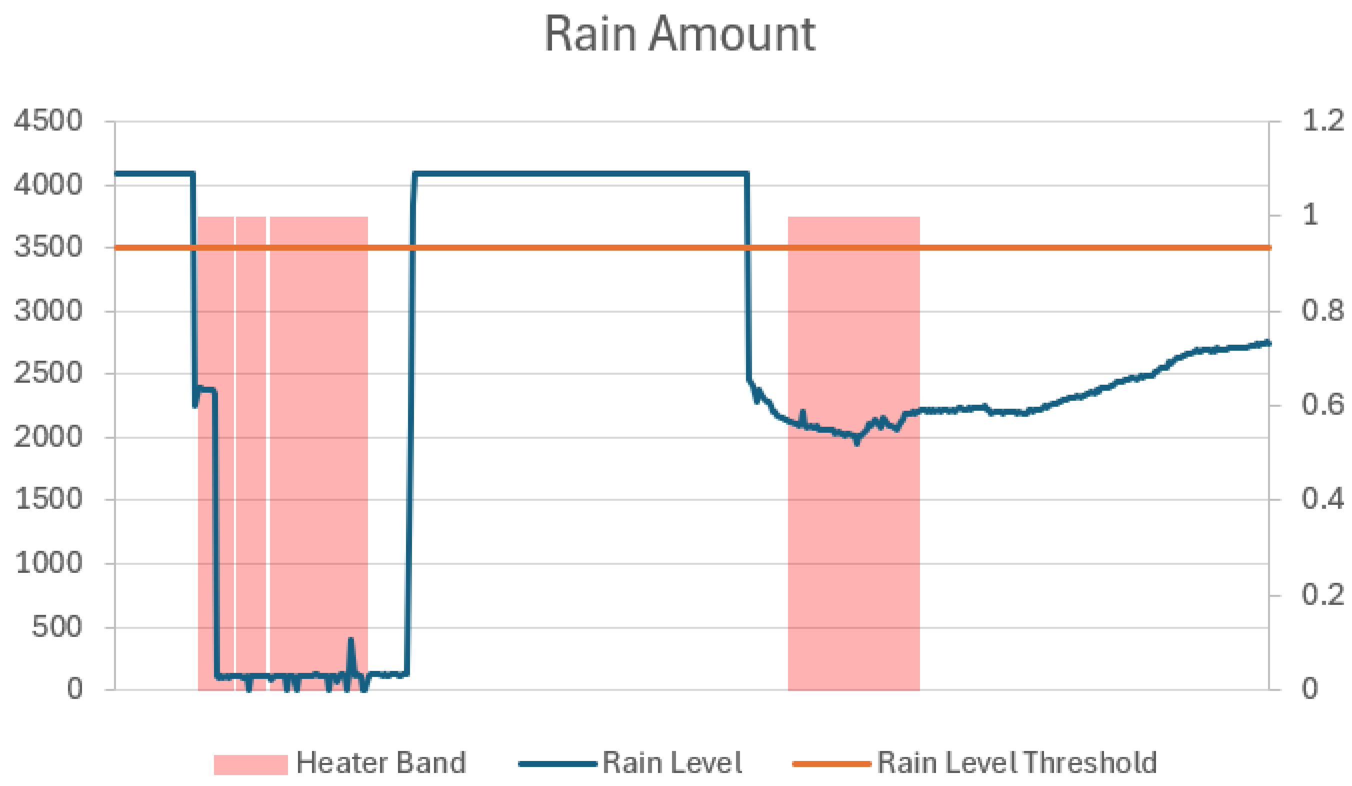
Graph of bridge surface temperature

Test Results (Surface Temperature Derivative)



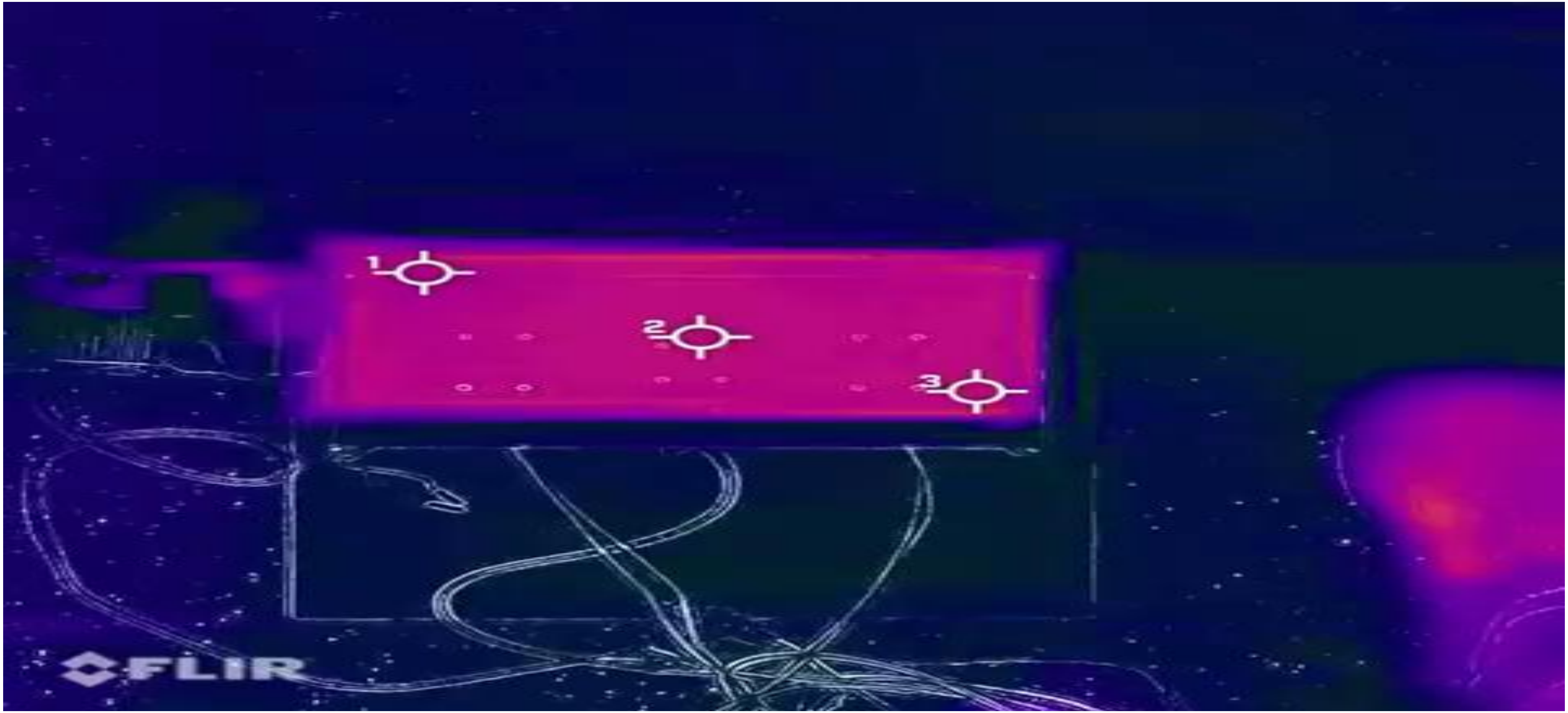
Graph of the rate of change of the surface temperature

Test Results (Precipitation)



Values of the rain sensor over the course of the test.

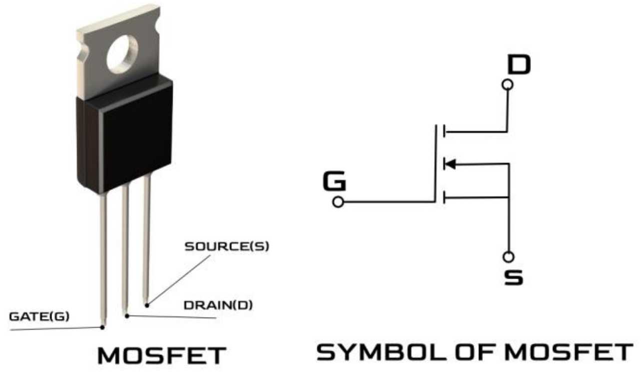
Test Results (Uniformity)



Successes and Challenges

Choosing the Right MOSFET

- Requirements:
  - ≤ 3.3V gate-source voltage
  - Low on-resistance and heat dissipation
  - Low junction temperature
  - Wide enough pins for 6A
- Choices:
  - IRLZ44NPBF
    - 10V recommended gate source voltage, 1.26W power dissipation
    - 103°C junction temperature.
  - IRLB8743PBF
    - 3.3V gate source voltage, 0.216W power dissipation
    - 38.4°C junction temperature
    - Pins not wide enough
  - CSD17312Q5
    - 3V gate source voltage, 0.0648W power dissipation, 28.18°C junction temperature
    - Wide pins handle 6A



Challenges: Simulated Cold Environment

Sub-Zero Environment Simulation

- We were unable to simulate an environment below 0°C
  - Dry ice: too expensive.
  - Normal ice: not cold enough.

- How we compensated:
  - Used ice to bring the surface temperature to near-zero.
  - Tested with larger amounts of ice in order to reduce the melting induced by the environment.

Successes: Power consumption and costs

Power Consumption

- Our prototype
  - Area: $50in^2 \approx 0.0323m^2$
  - Energy per use: 140W x 5mins = 11.6Wh ≈ 0.012kWh
  - Power density: $140W/0.0323m^2 = 4340W/m^2 = 4.34kW/m^2$
- Real World Scale
  - Area: $100\ m^2$
  - Industry Standard power density for concrete systems: $516W/m^2$
  - Power = Area x Density = 51.6kW
  - Energy = 51.6kW x 6 hours = 310kWh

Costs

- Estimates
  - Scaled Bridge: 310kWh x $0.20 = $62
  - Salting: Salt + Labor = ~$100 + $50 = $150
  - Plowing: Fuel + labor = $30 + $100 = $130
- Considerations
  - Maintenance
  - Upfront cost

Further Work

Further Improvements

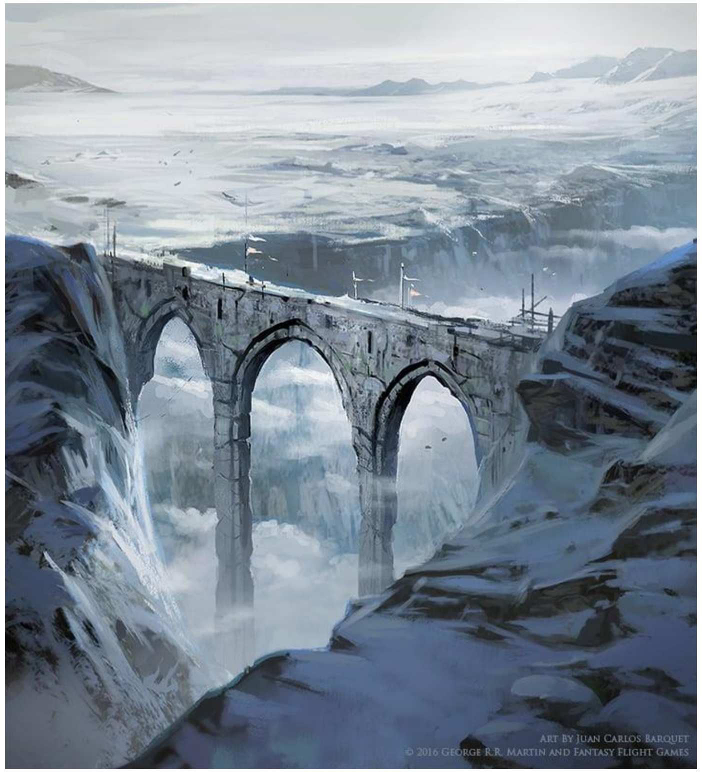
- Improve enclosure for weather resistance and durability in outdoor environment
- Add more temperature and rain sensors
- Investigate using solar panels
- Incorporate weather forecasting
- Drainage system

How Will This Scale?

- Could use a tillable model to fill an area the size of a real bridge.
  - Easy Maintenance
  - Smaller Cartridges: Safer Heating and Uniform Heating
- Could use alternative heating methods, such as hydrothermal.

Conclusions

- Reflections and Insights
  - Improve wire enclosure and wire management
  - Add insulation for efficiency
  - Read the documentation more closely
- Learnings
  - PCB design
  - Soldering
  - Testing and Simulation
  - Power delivery



Thank You!

Special thanks to Arne Fliflet, Jiankun Yang

The Grainger College of Engineering

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN