Comfort Monitoring Sensor Network

MIE1050

By: Souren Pashangpour, Sohrab Roointan

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Motivation and Problem

- Humans awake at ~23 °C (our “operating temperature”).
- For good sleep: Room must be ~ 2–3 °C cooler, so that body temperature drops
- Humidity should be around 50% RH
- Most people only adjust thermostat/window/fan right before bed
- Too late → room doesn’t reach 20 °C in time, often ends up too hot or too cold.
- Considers factors such as rain or snow outside → need constant adjustments to maintain the desired temperature

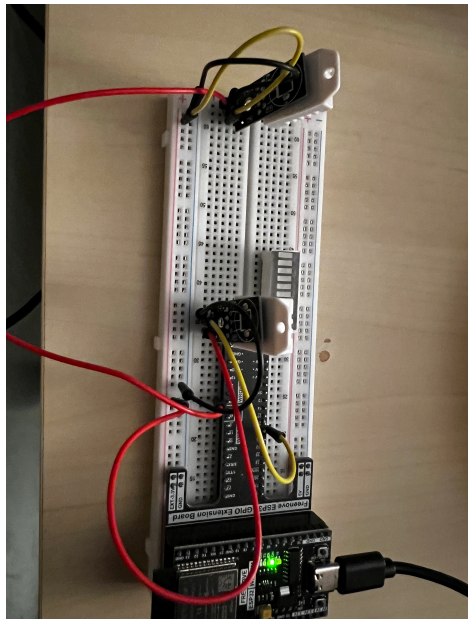
Proposed System

- An intelligent system that assists in speeding up sleep onset and shortening waking period (temp + humidity).
- The system should be proactive (deliberative) rather than reactive.
- The system should be able to learn from user habits, without a time investment from user.
- Adjusts automatically (thermostat, window state, fan, humidifier).

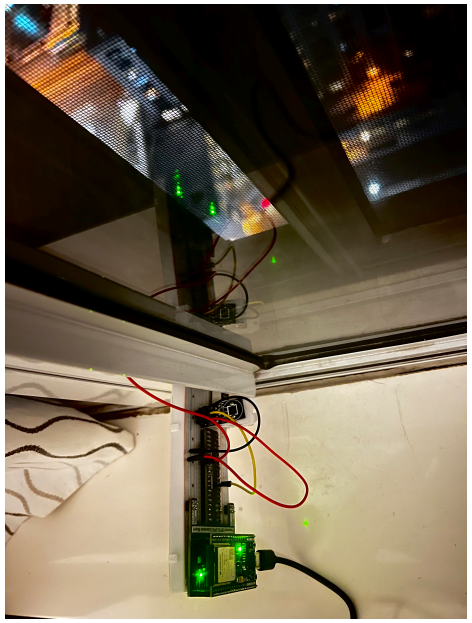
- **The proposed system will need to:**
  - Access sensor data to know the current room state (temp, humidity, light, noise).
  - Build a profile of the user's environment and habits automatically.
  - Learn a model of the room's thermal & humidity dynamics to estimate cooling/warming time.
  - Access actuators (thermostat, fan, window, humidifier) to adjust conditions.
  - Determine how long it will take to reach ideal sleep conditions.
  - Decide what actions to take and when to take them, *before* the user tries to sleep.

Sensing hubs

- 3 Esp 32 Nodes + 1 Server



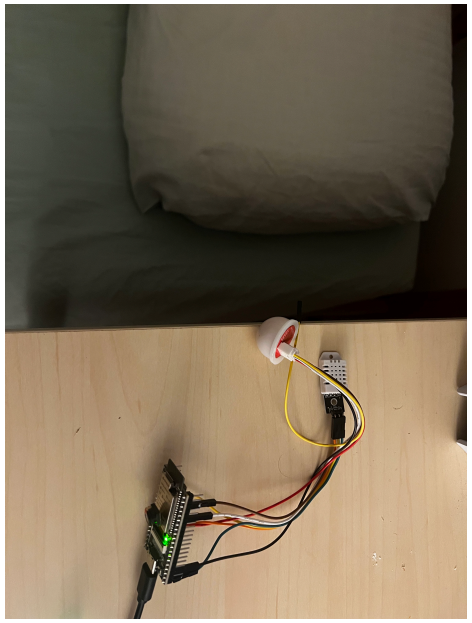
a.



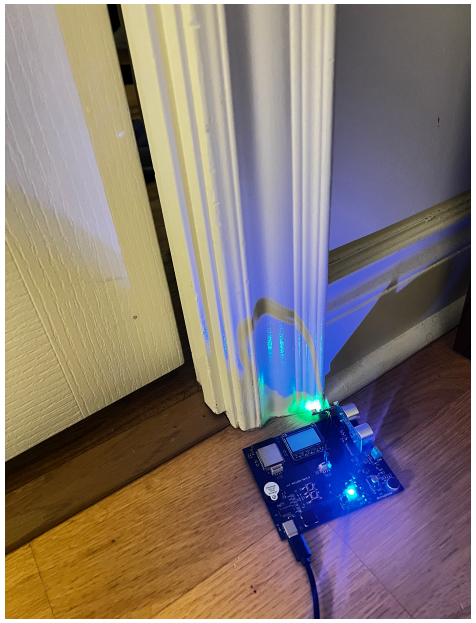
b.

Window:

- Outside vs inside temperature
- Outside vs inside humidity



a.



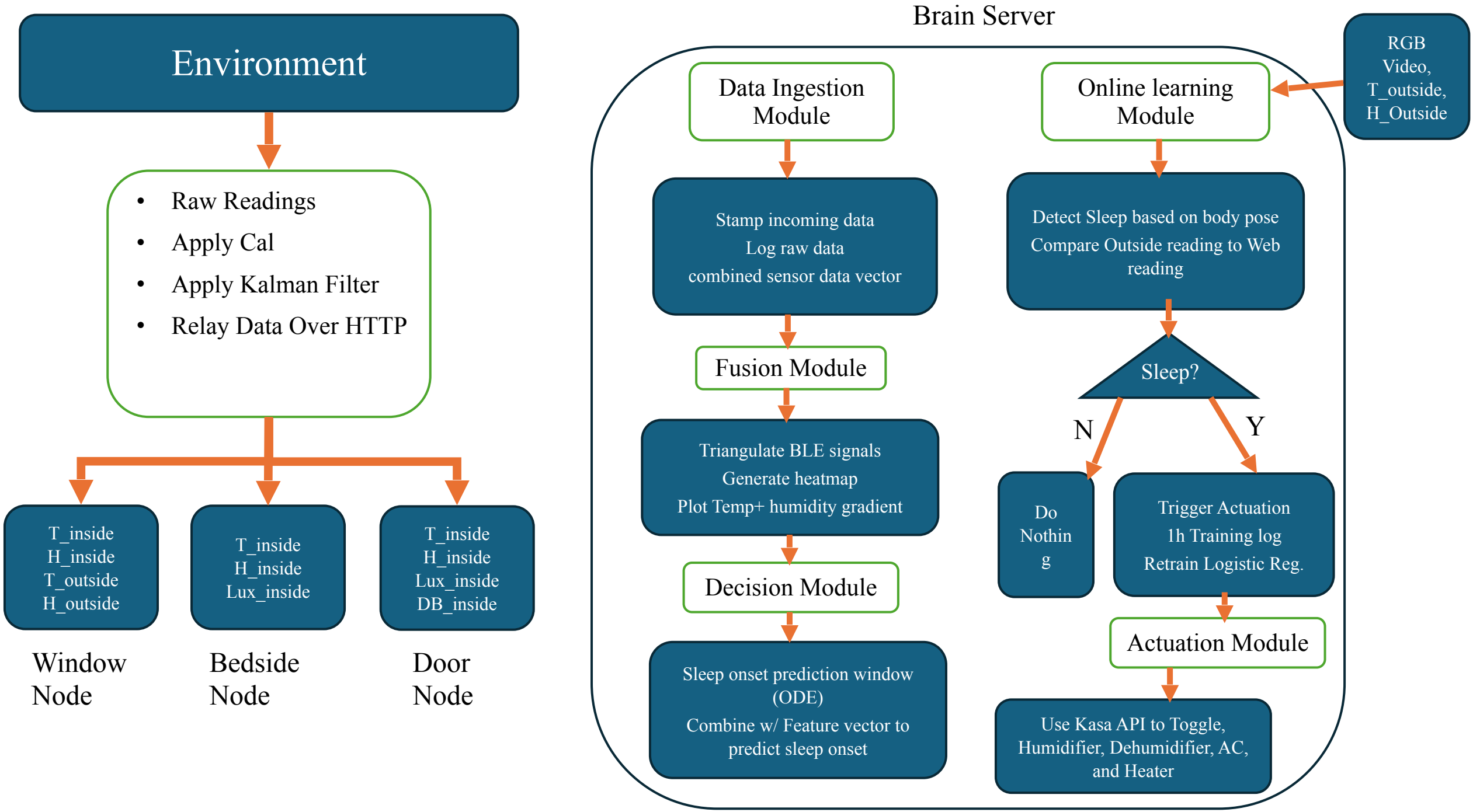
b.

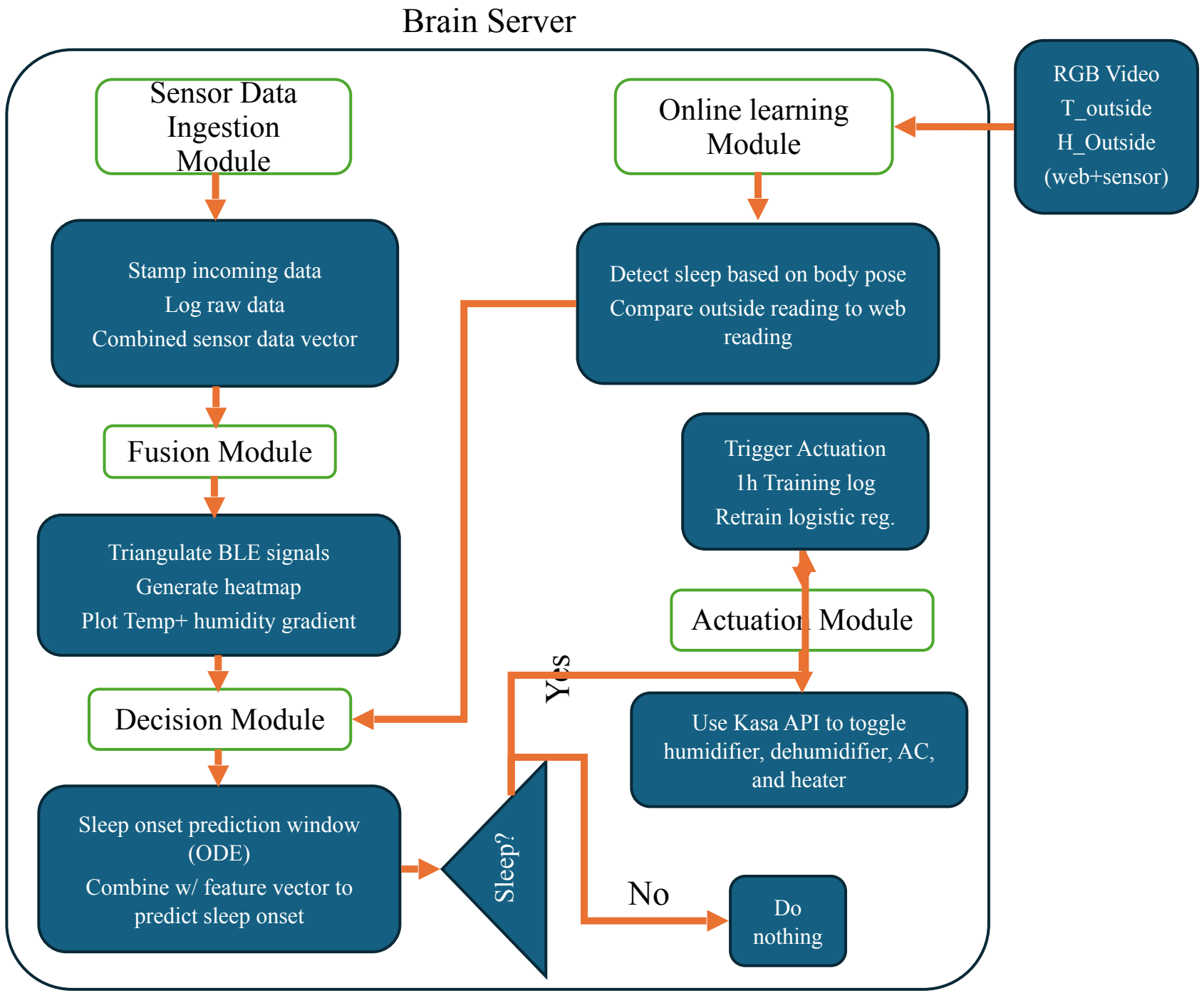
Bedside:

- Light
- Temperature
- Humidity

Door:

- Light
- Noise
- Humidity

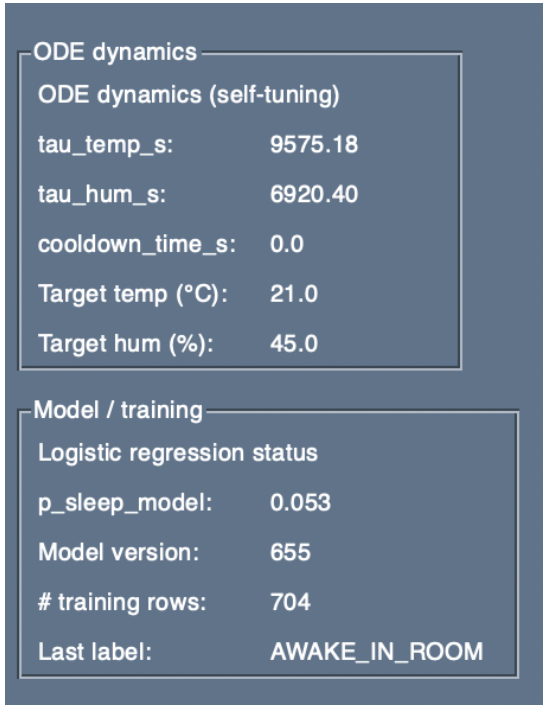

Environment
Raw Readings
Apply Cal
Apply Kalman Filter
Relay Data Over HTTP
T_inside
H_inside
T_outside
H_outside
Window Node
T_inside
H_inside
Lux_inside
Bedside Node
T_inside
H_inside
Lux_inside
DB_inside
Door Node
Brain Server
Data Ingestion Module
Stamp incoming data
Log raw data
combined sensor data vector
Fusion Module
Triangulate BLE signals
Generate heatmap
Plot Temp+ humidity gradient
Decision Module
Sleep onset prediction window (ODE)
Combine w/ Feature vector to predict sleep onset
Online learning Module
RGB Video, T_outside, H_Outside
Detect Sleep based on body pose
Compare Outside reading to Web reading
Sleep?
N
Y
Do Nothing
Trigger Actuation
1h Training log
Retrain Logistic Reg.
Actuation Module
Use Kasa API to Toggle, Humidifier, Dehumidifier, AC, and Heater

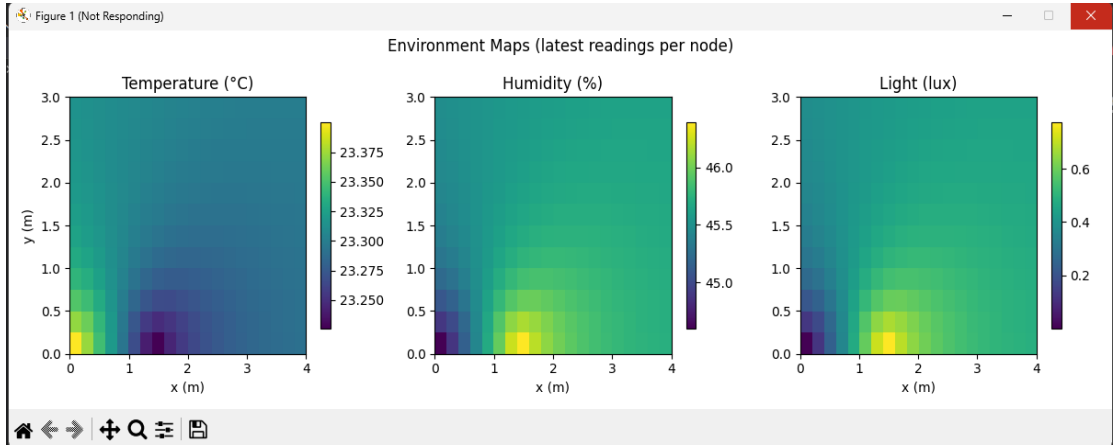

Brain Server
Sensor Data Ingestion Module
Stamp incoming data
Log raw data
Combined sensor data vector
Fusion Module
Triangulate BLE signals
Generate heatmap
Plot Temp+ humidity gradient
Decision Module
Sleep onset prediction window (ODE)
Combine w/ feature vector to predict sleep onset
Sleep?
Yes
No
Do nothing
Online learning Module
RGB Video
T_outside
H_Outside
(web+sensor)
Detect sleep based on body pose
Compare outside reading to web reading
Trigger Actuation
1h Training log
Retrain logistic reg.
Actuation Module
Use Kasa API to toggle humidifier, dehumidifier, AC, and heater

Under the hood

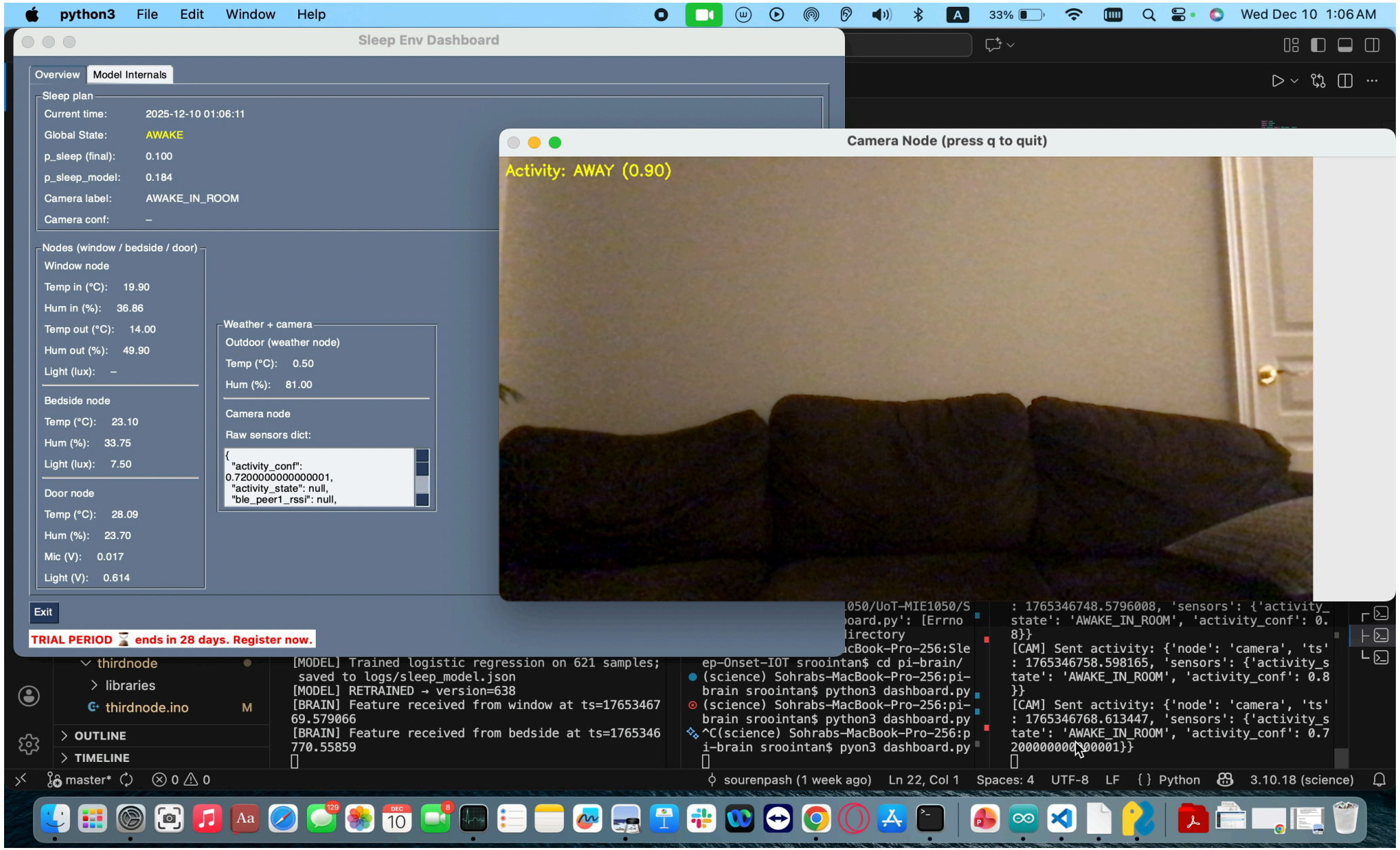
- **Calibration**
  - Linear correction: **actual = a·raw + b**
- **Kalman Filtering**
  - 1-D Kalman filter per signal
  - Assume only Light and Mic change quickly, and all sensors to be relatively low noise:

    Temp: Q=0.01, R=0.2 Humidity: Q=0.01, R=1.0 Light: Q=0.05, R=5.0 Mic: Q=0.1, R=10.0
- **Sensor Output**
  - Every 10 seconds: send fused JSON packet → server
  - Includes: calibrated + filtered T, RH, mic, light, BLE RSSI, timestamp
  - Connection maintained via TCP; auto-reconnect if dropped
- **ODE**
  - dT/dt=−(T−T_out)/Tt T(t)=T_out+(T_0−T_out)*e^-(t/τT)
  - Use the most recent Tau to solve for time from current temperature to target temperature
- **Spatio/Temporal Map**
  - Temperature only known at a few sensor nodes
  - Compute its distance to each sensor.
  - Use inverse-distance weighting (1/d) to assign weights.
  - Take a weighted average of sensor temperatures.



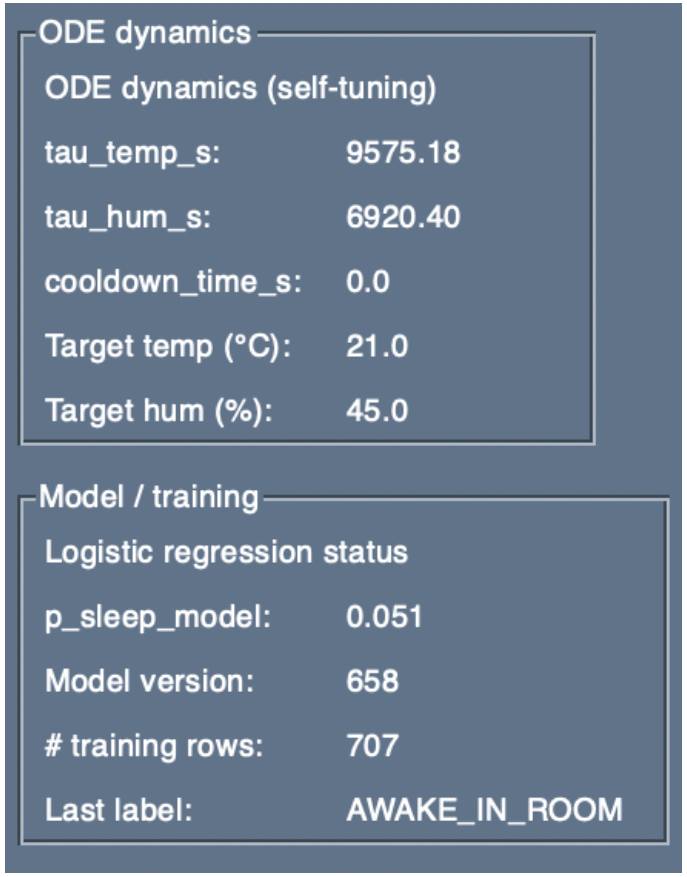


Demo Time!

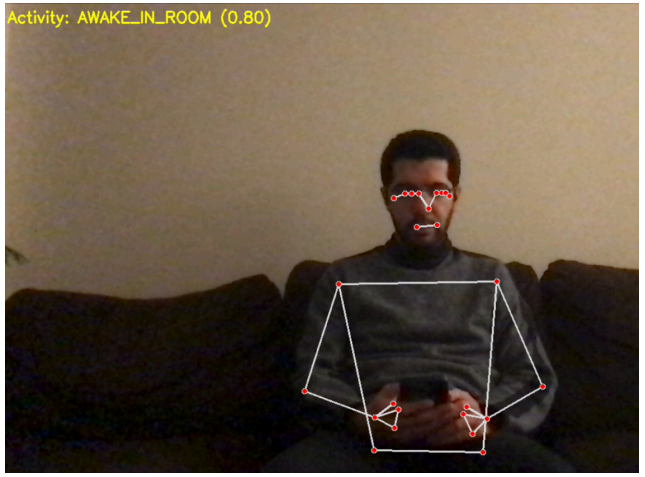

python3 File Edit Window Help
33% Wed Dec 10 1:06 AM
Sleep Env Dashboard
Overview
Model Internals
Sleep plan
Current time: 2025-12-10 01:06:11
Global State: AWAKE
p_sleep (final): 0.100
p_sleep_model: 0.184
Camera label: AWAKE_IN_ROOM
Camera conf: –
Nodes (window / bedside / door)
Window node
Temp in (°C): 19.90
Hum in (%): 36.86
Temp out (°C): 14.00
Hum out (%): 49.90
Light (lux): –
Bedside node
Temp (°C): 23.10
Hum (%): 33.75
Light (lux): 7.50
Door node
Temp (°C): 28.09
Hum (%): 23.70
Mic (V): 0.017
Light (V): 0.614
Weather + camera
Outdoor (weather node)
Temp (°C): 0.50
Hum (%): 81.00
Camera node
Raw sensors dict:
{
"activity_conf": 0.7200000000000001,
"activity_state": null,
"ble_peer1_rssi": null,
Exit
TRIAL PERIOD ⌛ ends in 28 days. Register now.
Camera Node (press q to quit)
Activity: AWAY (0.90)
thirdnode
libraries
thirdnode.ino M
OUTLINE
TIMELINE
[MODEL] Trained logistic regression on 621 samples; saved to logs/sleep_model.json
[MODEL] RETRAINED → version=638
[BRAIN] Feature received from window at ts=1765346769.579066
[BRAIN] Feature received from bedside at ts=1765346770.55859
(science) Sohrabs-MacBook-Pro-256:pi-brain sroointan$ python3 dashboard.py
(science) Sohrabs-MacBook-Pro-256:pi-brain sroointan$ python3 dashboard.py
^C(science) Sohrabs-MacBook-Pro-256:pi-brain sroointan$ pyon3 dashboard.py
[CAM] Sent activity: {'node': 'camera', 'ts': 1765346748.5796008, 'sensors': {'activity_state': 'AWAKE_IN_ROOM', 'activity_conf': 0.8}}
[CAM] Sent activity: {'node': 'camera', 'ts': 1765346758.598165, 'sensors': {'activity_state': 'AWAKE_IN_ROOM', 'activity_conf': 0.8}}
[CAM] Sent activity: {'node': 'camera', 'ts': 1765346768.613447, 'sensors': {'activity_state': 'AWAKE_IN_ROOM', 'activity_conf': 0.7
master* 0 0 sourenpash (1 week ago) Ln 22, Col 1 Spaces: 4 UTF-8 LF { } Python 3.10.18 (science)


Overview
Model Internals
Sleep plan
Current time: 2025-12-16 18:53:02
Global State: AWAKE
p_sleep (final): 0.051
p_sleep_model: 0.051
Camera label: AWAKE_IN_ROOM
Camera conf: –
Nodes (window / bedside / door)
Window node
Temp in (°C): 19.88
Hum in (%): 37.12
Temp out (°C): 13.40
Hum out (%): 50.10
Light (lux): –
Bedside node
Temp (°C): 23.15
Hum (%): 33.52
Light (lux): 5.00
Door node
Temp (°C): 28.16
Hum (%): 23.60
Mic (V): 0.015
Light (V): 0.618
Weather + camera
Outdoor (weather node)
Temp (°C): 0.50
Hum (%): 81.00
Camera node
Raw sensors dict:
{
"activity_conf": 0.8,
"activity_state": null,
"ble_peer1_rssi": null,
"ble_peer2_rssi": null,
Exit

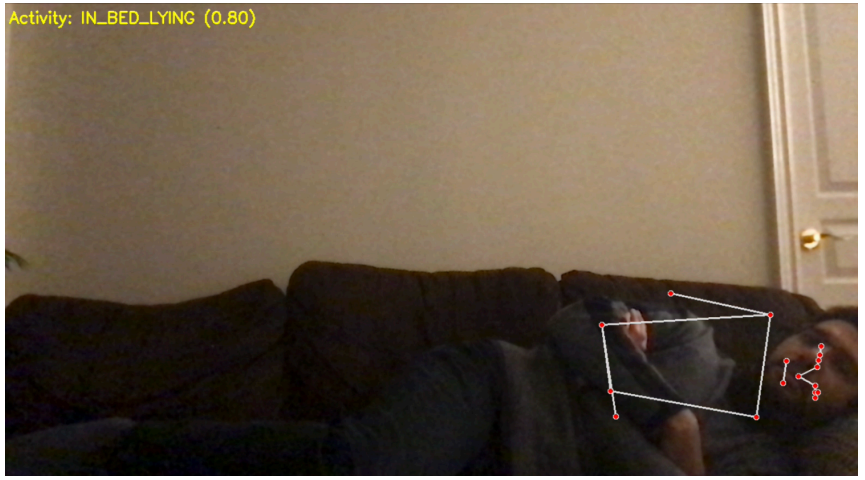
a.


ODE dynamics
ODE dynamics (self-tuning)
tau_temp_s: 9575.18
tau_hum_s: 6920.40
cooldown_time_s: 0.0
Target temp (°C): 21.0
Target hum (%): 45.0
Model / training
Logistic regression status
p_sleep_model: 0.051
Model version: 658
training rows: 707
Last label: AWAKE_IN_ROOM

b.


Activity: AWAKE_IN_ROOM (0.80)

a.


Activity: IN_BED_LYING (0.80)

b.

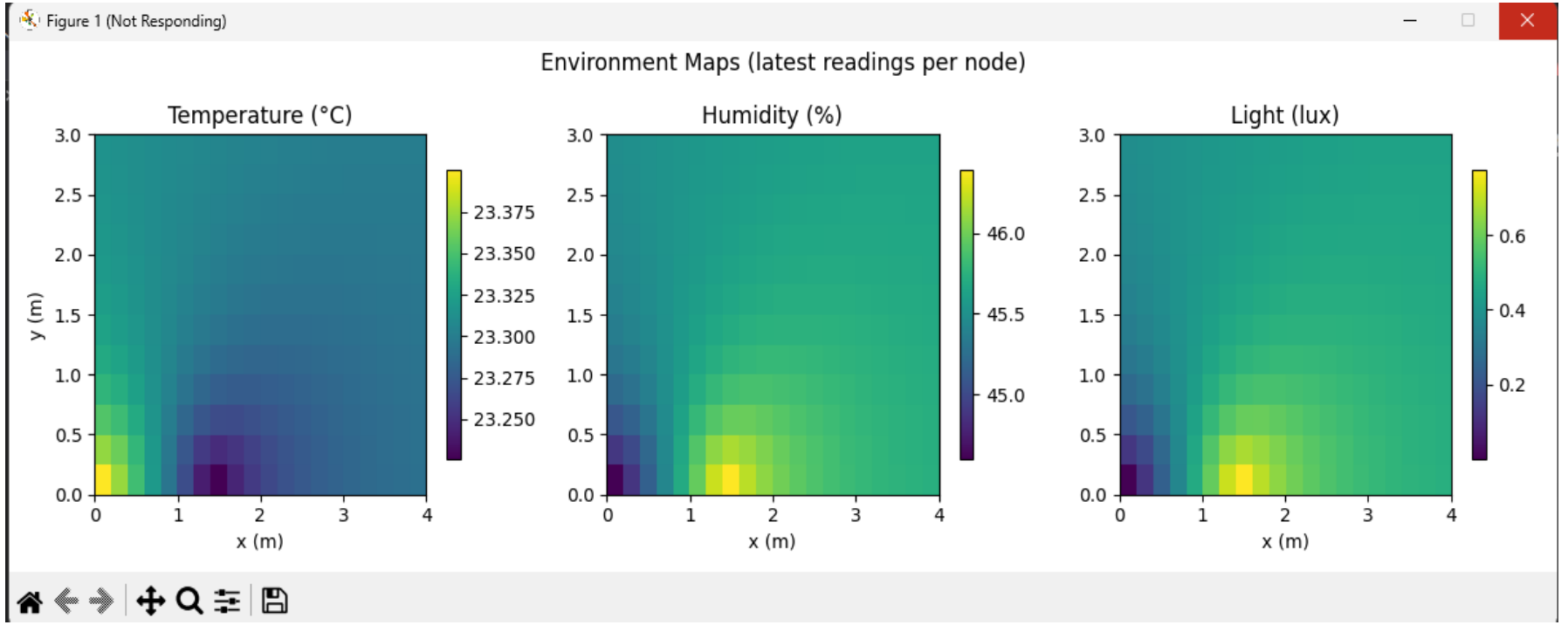


Figure 1 (Not Responding)
Environment Maps (latest readings per node)
Temperature (°C)
Humidity (%)
Light (lux)
y (m)
x (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
1
2
3
4
23.375
23.350
23.325
23.300
23.275
23.250
46.0
45.5
45.0
0.6
0.4
0.2