Renewable Energy Lab Weather Station

By:

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Project Description

The goal of this project is to make a weather station for the RE Lab at NAU that will last for years. This station will provide accurate and current measurements for various weather conditions and will be accessible from anywhere with an internet connection.

Measure:

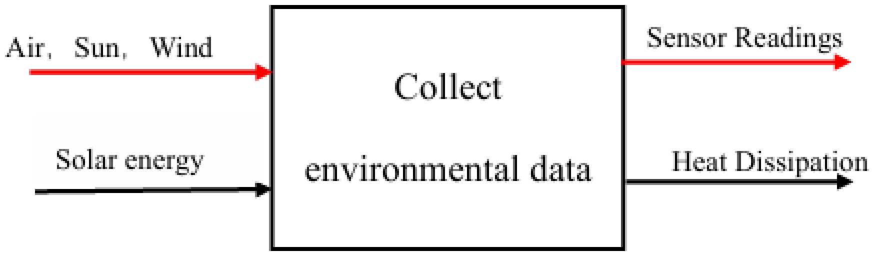
- Temperature
- Humidity
- Wind Speed/Direction
- Barometric Pressure
- Solar Irradiance
- Possibly Rainfall

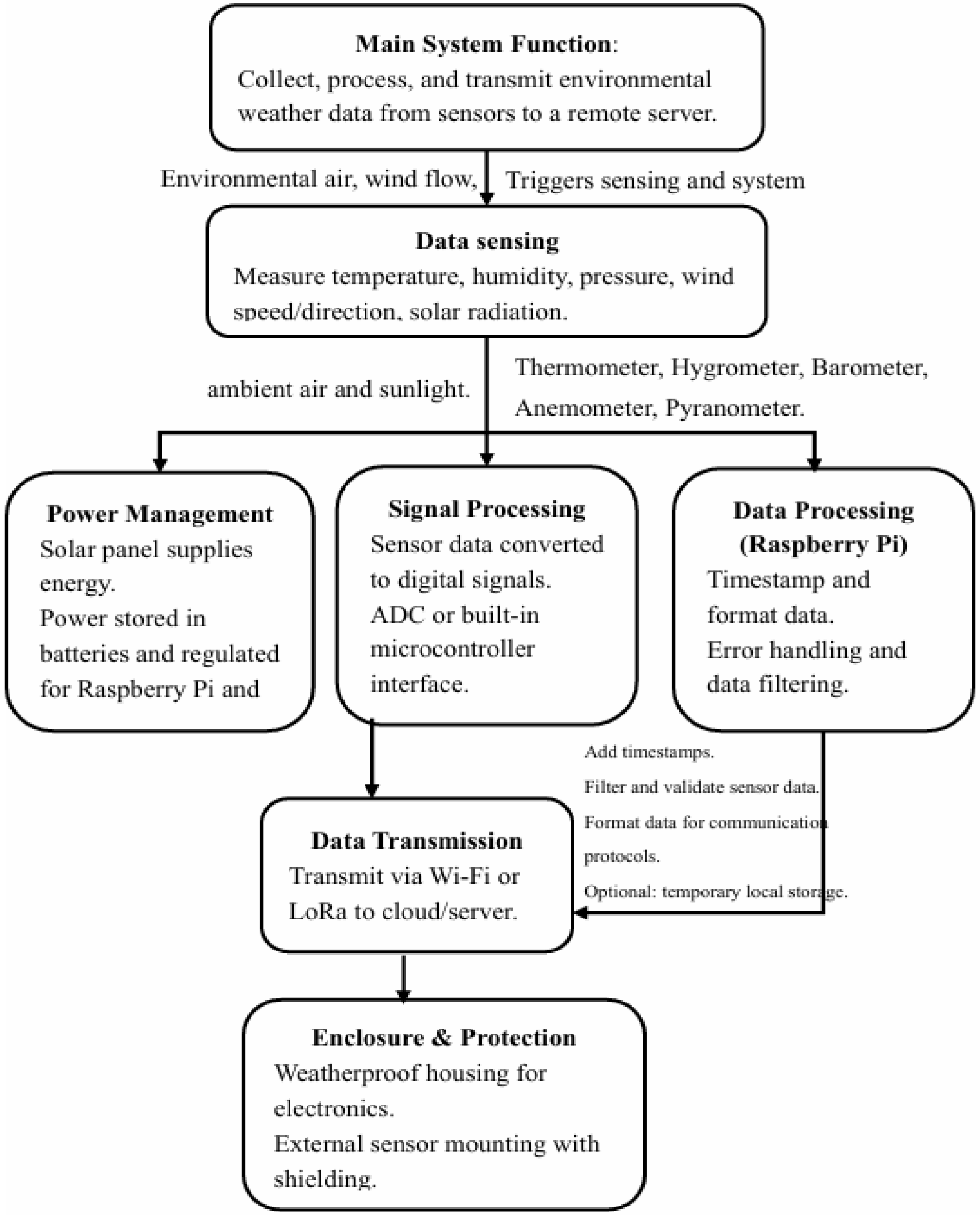
Purpose:

For academic use within the Wind Power and Renewable Energy courses. Weather stations are important for weather forecasts, disaster preparedness, and agricultural information.

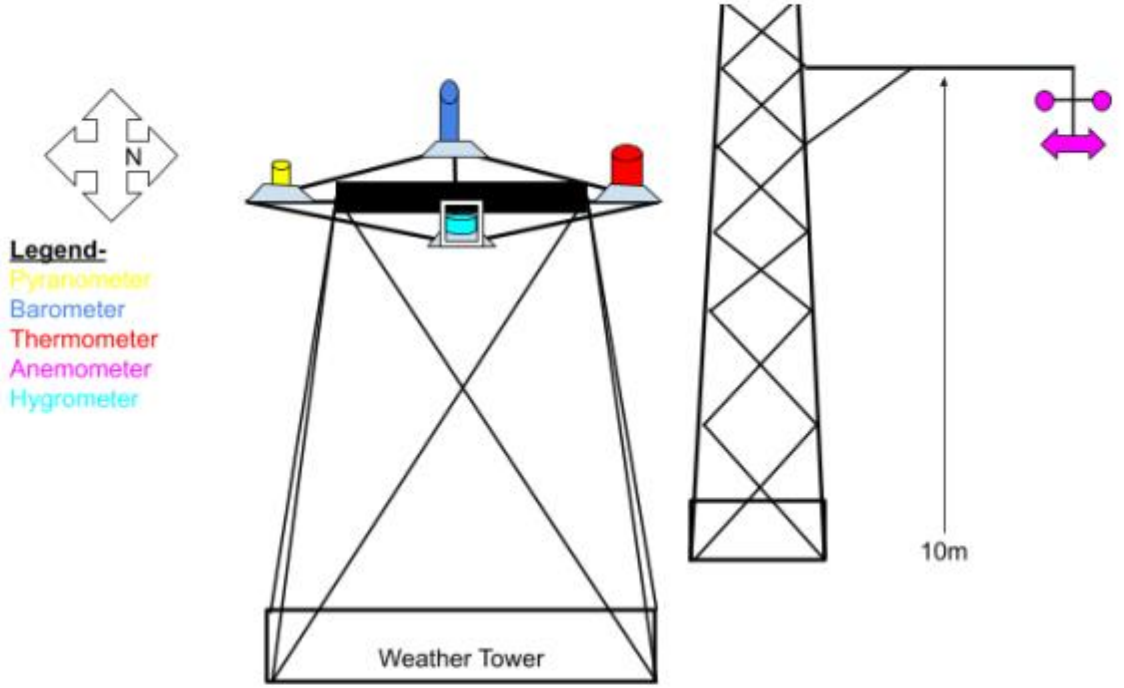
Functional Decomposition

The functional decomposition diagram helps us break down the weather station into its core tasks: sensing, processing, data handling, transmission, power supply, and protection. It clarifies the system logic, facilitates task allocation, highlights challenges such as A/D conversion and power regulation, and supports modular design for easier testing, upgrading, and maintenance.





Concept Generation



Structural Design - DATUM

Pros:

- Stability
- Adherence to industry standards
- Low cost
- Durable

Cons:

- Crossbar must be built
- Boom installation may be difficult
- Potential safety hazard

Pseudocode Design – Design 3

Rolling 10-minute average updated every minute on website as live data.

Hourly buffer saved in Raspberry Pi and averaged for database upload.

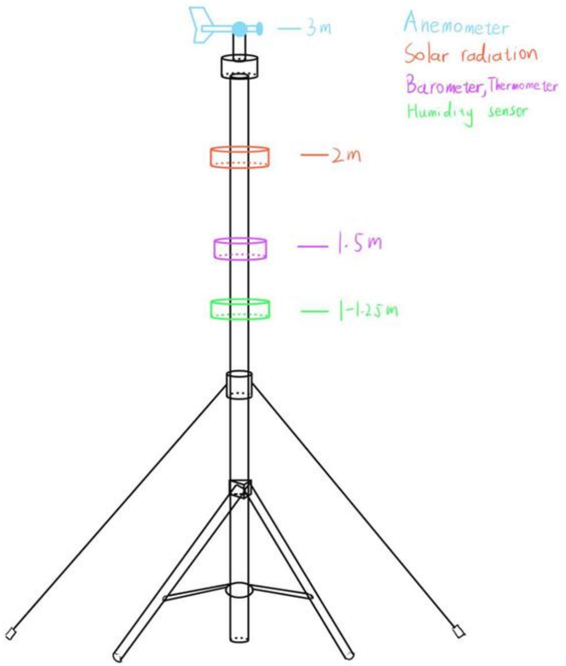
Pros:

- Access to accurate, live data
- Low storage requirement
- Easy to implement

Cons:

- Less precise database
- High sensor reading frequency
- Low data backup

Concept Generation



Structure – Design 1

Pros:

- Modular structure allows for easy replacement and calibration
- Cable built-in aesthetically pleasing weatherproof
- Easy to maintain

Cons:

- Many things need to be built
- Insufficient height may affect some sensors
- Lightweight design, wind resistance rating may be lower.

Pseudocode Design – Design 1

Core Logic:

- Sampling is done every 10 minutes, and humidity data is added with abnormal judgment
- All data is first saved locally and then uploaded individually by sensor
- Clear cache and generate running reports daily

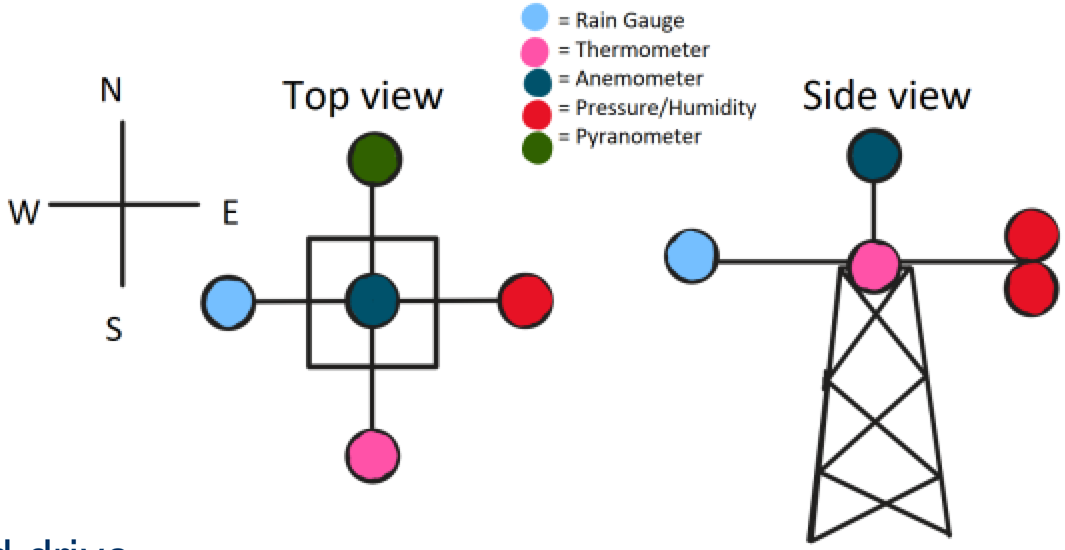
Pros:

- Automatically reduce frequency in a stable environment to save energy
- Outlier Identification Improves Accuracy
- Offline caching ensures data is not lost

Cons:

- Additional code needs to be written to monitor data changes
- Raspberry Pi handles rising pressure
- Increasing the sampling interval may cause the real-time performance of data to decrease

Concept Generation



Structure – Design 3

- Pros
  - All on one body
  - Easy maintenance
  - Most Standards met
- Cons
  - Anemometer not at standard
  - Flimsy connection points
  - Must build mounting hardware

Storage - DATUM
2 TB external hard drive

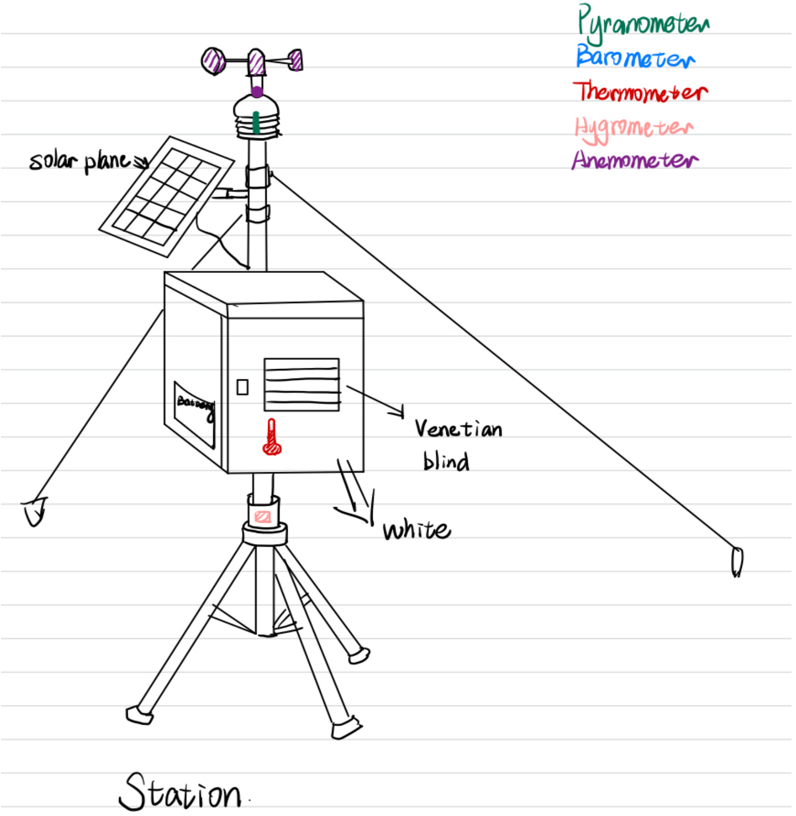
- Pros
  - Massive storage
- Cons
  - Extra expense
  - More power consumption
  - Bigger footprint

Pseudocode – DATUM
5 minutes upload, no extra code for power consumption or storage capacity.

- Pros
  - Simple
  - Low power
- Cons
  - Lots of data collected
  - Very frequent uploads, high bandwidth

Concept Generation

A compact weather station built on a tripod with a vertical mast. All sensors—including anemometer, wind vane, thermometer, hygrometer, barometer, and solar panel—are mounted centrally. Temperature, humidity, and pressure sensors are housed in a white louvered Stevenson screen to reduce solar interference.



Pros:

- Small footprint
- Fast deployment
- Centralized power and data routing

Cons:

- Anemometer height below 10-meter industry standard
- May reduce wind data accuracy

Pseudocode:

- Load data from CSV
- Clean and convert timestamps
- Filter: temperature (–50°C to 60°C), pressure (800–1100 hPa)
- Keep only last 24 hours
- Plot and save temperature and pressure charts

Pros:

- Clear data filtering and validation
- Easy to use and implement
- Quick visualization of recent data

Cons:

- No live streaming or database upload
- Only visual output, no backups
- Supports temperature and pressure only

Previous Engineering Calculations

Power Consumption :

- Required: < 0.2 kwh per day as per Engineering Requirement
- Calculated: 0.1704 kwh per day
- Validated through NiuBol [6]

Thermometer Calibration Equation:

- Inverse Eq for temperature output:
- Based on IEC 60751 Specification
- Contributes to calibration engineering requirement.

$$t = -\frac{A}{2B} + \frac{A}{2B}\sqrt{1 - \frac{4B}{A^2}\left(1 - \frac{R}{R_0}\right)}$$

Thermal Management Calculation

Joule heating

$\Delta T = P * R\_\theta JA$

Solar Radiation

$Q\_solar = G*A*\alpha$

Humidity Calibration Equation

$$RH = \frac{216-180}{250-180} \times 100 = \frac{36}{70} \times 100 = 51.4\%$$

- Example equation generated with non-measured values
- Contributes to calibration QFD requirement
- Validated through comparison to manufacturer's Calibration curve.

Engineering Calculations

Anemometer Uncertainty Calculation:

- Generated random wind speed data
- Falls within our 3% accuracy requirement

```matlab
% Number of wind speed samples to generate
num_samples = 50;

% Generate random wind speeds between 4 and 26 m/s
wind_speeds = 4 + (26 - 4) * rand(num_samples, 1);

% Fixed or assumed uncertainty components (in %)
U_V_percent = 0.5;      % Reference wind speed uncertainty (constant)
U_IUT_percent = 1.0;    % Anemometer output uncertainty (constant)
% Linear regression uncertainty (variable, simulate variability)
U_LR_percent = 0.2 + (1.0 - 0.2) * rand(num_samples, 1);  % between 0.2% and 1.0%

% Calculate total uncertainty for each sample
U_cal_percent = sqrt(U_V_percent^2 + U_IUT_percent^2 + U_LR_percent.^2);

% Convert percent uncertainty to absolute uncertainty in m/s
U_cal_abs = (U_cal_percent ./ 100) .* wind_speeds;

% Display results in a table
T = table(wind_speeds, U_LR_percent, U_cal_percent, U_cal_abs, ...
    'VariableNames', {'WindSpeed_mps', 'ULR_percent', 'Ucal_percent', 'Ucal_mps'});
```

```matlab
(m/s)');
 vs Wind Speed');
```

Anemometer Calibration Uncertainty	$U_{cal} = \sqrt{(U_V)^2 + (U_{IUT})^2 + (U_{LR})^2}$	~ 0.7% to 5.2%
Reference Wind Speed Uncertainty	$U_V = \sqrt{(B_V)^2 + (tS_V)^2}$	~ 0.5%
Anemometer Output Uncertainty	$U_{IUT} = \sqrt{B_{IUT}^2 + (tS_{IUT})^2}$	~ 0.5% to 1.5%
Linear Regression Uncertainty (Case 1)	$U_{LR} = \sum_{i=1}^{N} t\frac{STE_V}{V_i}$	~ 0.2% to 5.0 %
Linear Regression Uncertainty (Case 2)	$U_{LR} = \sqrt{\left(t\frac{STE_m}{V_i} f_i\right)^2 + \left(t\frac{STE_b}{V_i}\right)^2}$	~ 0.2% to 5.0 %

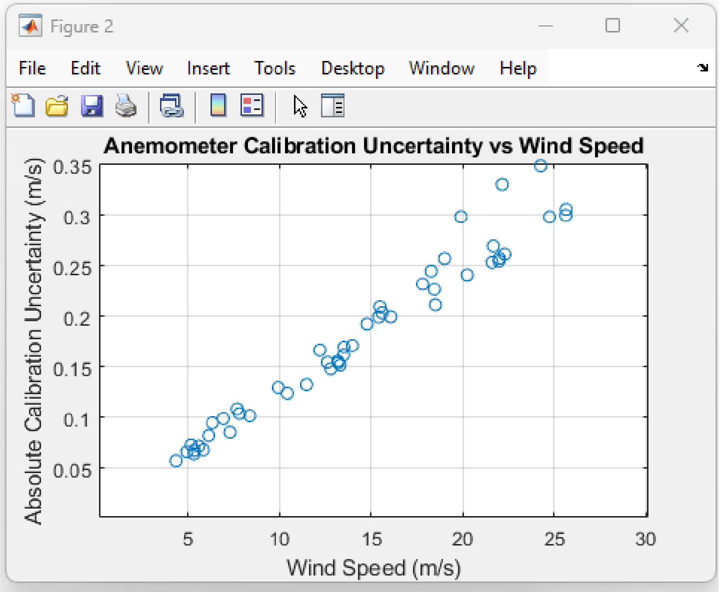
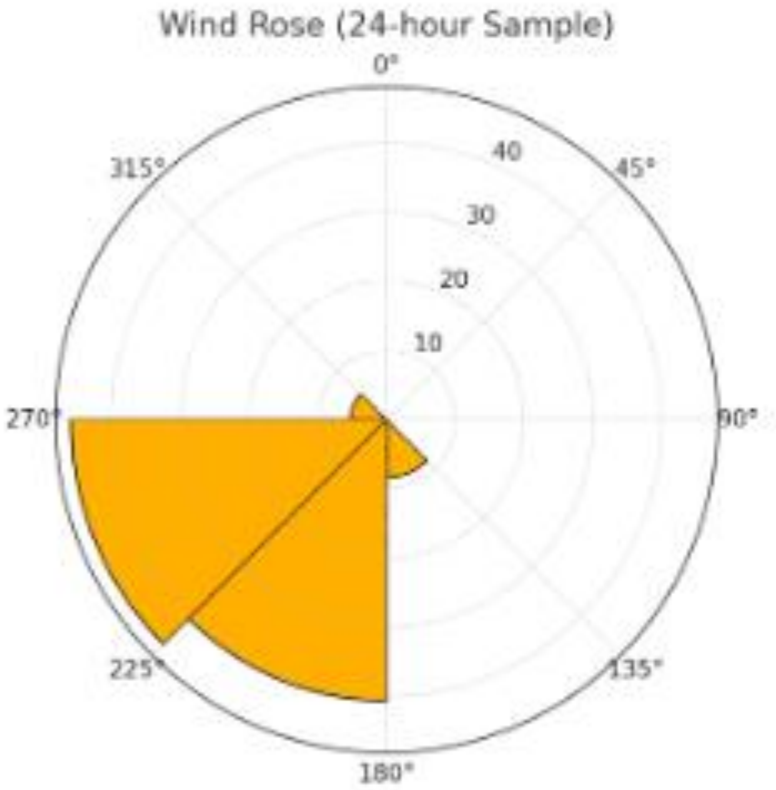


Figure 1

	WindSpeed_mps	ULR_percent	Ucal_percent	Ucal_mps
1	18.1750	0.9705	1.4805	0.2691
2	12.3294	0.6374	1.2870	0.1587
3	21.8548	0.6169	1.2769	0.2791
4	15.7222	0.3853	1.1826	0.1859
5	11.7160	0.5911	1.2647	0.1482
6	24.6580	0.6992	1.3187	0.3252
7	23.2707	0.7433	1.3426	0.3124
8	16.1034	0.5164	1.2315	0.1983
9	17.6945	0.4939	1.2223	0.2163
10	16.9150	0.9904	1.4936	0.2526

Engineering Calculations

- Wind direction data over a 24-hour period was grouped into 8 primary compass bins: N, NE, E, SE, S, SW, W, and NW. The result is presented as a polar wind rose chart, illustrating the frequency of occurrence for each direction.



Metric	Value	Explanation of Calculation
Dominant Direction (°)	225	The wind direction data was grouped into 8 compass bins (each 45° wide). The bin with the highest count is considered the dominant wind direction. In this case, 225°, corresponding to SW, occurred most frequently.
Max Direction Change (°)	100.02	Calculated by taking the absolute difference between each pair of consecutive wind direction samples. Since direction is circular, differences >180° are wrapped around using: diff=360−diff. The maximum of these values is reported here.
Mean Direction Change (°)	34.56	The average of the absolute values of the differences between consecutive direction samples, accounting for circular wrap-around. It reflects the average rate of directional fluctuation over time.

Wind Vane – Directional Change Analysis

1. **Dominant Direction**
- The direction with the highest frequency in the 24-hour data sample
- Example (from current data): 225° (i.e., SW)

2. **Angular Deviation**
- Computed deviation of each sample from dominant direction
- Values wrap around circularly (e.g., 350° → 10° diff from 0°)

3. **Change Rate Analysis**
- Consecutive direction differences captured
- Helps detect sudden wind shifts (useful for storm detection)

Engineering Calculations

Humidity Sensor Uncertainty

Uncertainty Model:

$$U_{total} = \sqrt{U_{cal}^2 + U_{temp}^2 + U_{linearity}^2}$$

Components:

- Assume a calibration uncertainty of ±2.00% RH.
- The temperature compensation error caused by a ±5°C deviation is ±0.25% RH.
- Sensor linearity contributes ±1.50% RH.
- The resulting combined uncertainty is approximately ±2.51% RH.

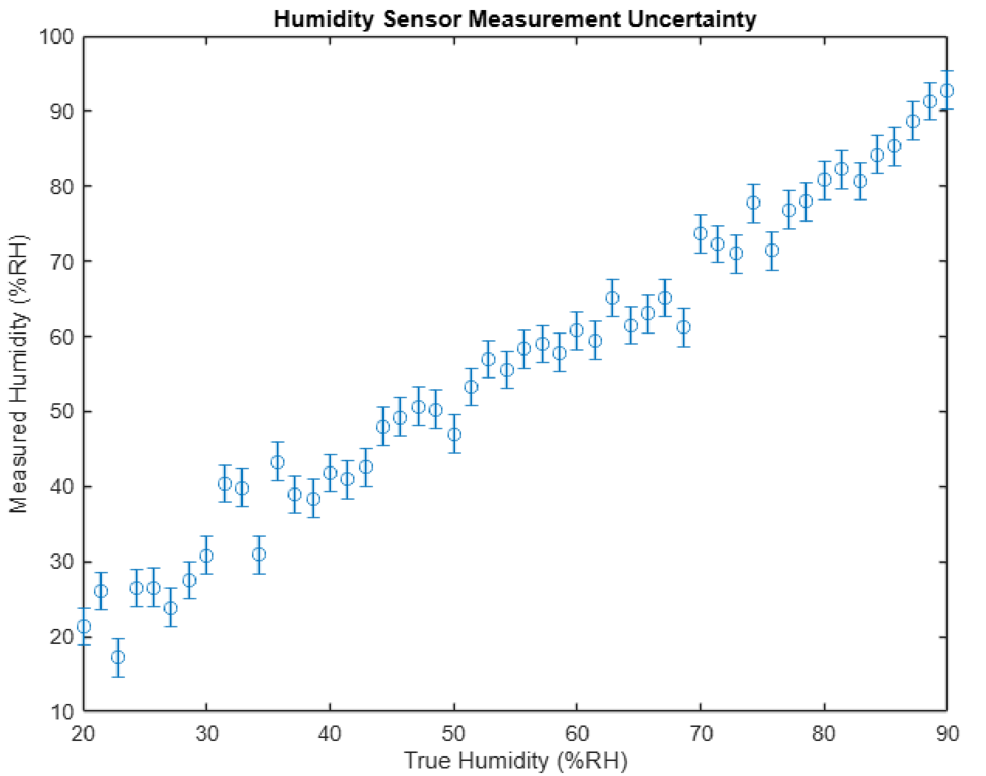
Simulation:

- 50 humidity readings were simulated between 20% and 90% RH.
- Add random noise according to the total uncertainty.
- A scatter plot with error bars visualizes the uncertainty in the sensor measurements.

```
true_RH = linspace(20, 90, 50);
U_cal = 2; % calibration ±2% RH
U_temp = 0.05 * 5; % ±5°C offset
U_linearity = 1.5; % non-linear effect
U_total = sqrt(U_cal^2 + U_temp^2 + U_linearity^2);

measured_RH = true_RH + randn(1,50) * U_total;
errorbar(true_RH, measured_RH, U_total * ones(1,50), 'o')
xlabel('True Humidity (%RH)')
ylabel('Measured Humidity (%RH)')
title('Humidity Sensor Measurement Uncertainty')

```



Engineering Calculations

Storage Estimation:

Data is SMALL [22] [23]

- 1 Character = 1 Byte
- 1 Kilobyte = 1000 Bytes
- 1 Megabyte = 1000 Kilobytes
- 1 Gigabyte = 1000 Megabytes

Each sensor will produce a total of 7 stored data points per hour

Assuming each data point is 5 significant figures: each sensor produces 35 bytes of data per hour that will be stored.

35 bytes / hour * 7 sensors * 24 hours = 5.88 Kilobytes per day

5.88 kB / day * 365 days / year = 2.146 mB per year

To meet our goal of 4 years of stored data, we would only need about 10 mB of extra storage.

A small 1-2 gigabyte SD card will easily cover the storage of our data as well as the size of the code that produces the data points.

Concept Evaluation

Structural Criteria:

- Weather Durability – Will the structure last for years through inclement weather?
- Safety Compliance – Does the structure pose any safety hazards?
- Low Maintenance – Will the structure require replacement parts or rebuilding down the line?
- Easy Installation – Is our team capable of installing the structure without outside help?
- Multiple Windspeed Readings – Does the structure provide an anemometer reading?
- Measured at Industry Standards – Do the sensor positions align with industry standards?

Pseudocode Criteria:

- Long Term Data Storage – Will the frequency of data recording facilitate long term storage?
- Increased Data Accuracy – Will the averaging technique provide accurate data points?
- Remote Data Access – Can a user check the website for live weather data?
- User Friendly – Is the data easy to access? Will the code be easy to implement?
- Low Power Requirement – Will the data reading frequency lead to increased power consumption?
- Data Transmission – Will the Raspberry Pi be able to transmit data?

Specification Table

Specification:	DATUM	Design 1 (Chenxi)	Design 2 (Shutong)	Design 3 (Ian)
Anemometer at 10m	Y	N	N	N
Sunlight exposure for pressure, solar irr, temperature sensor	Y	N	N	Y
Pressure, solar irr, humidity sensors at 6-10ft	Y	N	N	Y
No sunlight for humidity sensor	Y	Y	Y	Y
No wind currents for barometer	Y	N	N	Y
Thermometer at least 100m from extensive concrete	N	N	N	N
Thermometer at 4-6ft	N	Y	Y	N
40ft from obstructions	N	N	N	N

Pugh Chart

Structural:

- DATUM and Design 1 (by team tiebreaker vote) move on to decision matrix

Pseudocode:

- Design 1 and Design 3 move on to decision matrix

Pugh Chart

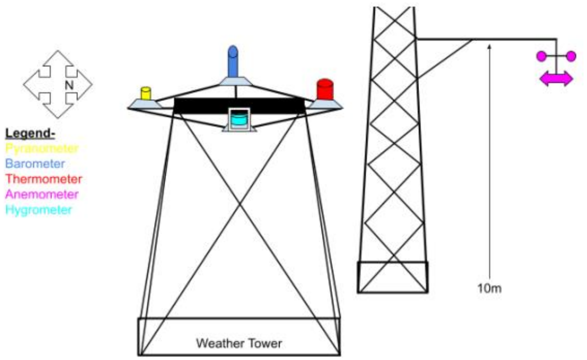
Criteria	DATUM (Rowan)	Design 1 (Chenxi)	Design 2 (Shutong)	Design 3 (Ian)
Weather Durability	0	-1	1	-1
Safety Compliance	0	1	1	0
Low Maintenance	0	0	-1	0
Easy Installation	0	0	-1	0
Multiple Windspeed Readings	0	0	0	0
Measured at Industry Standards	0	-1	-1	-1
	Totals	-1	-1	-2
	Rank	2	2	4

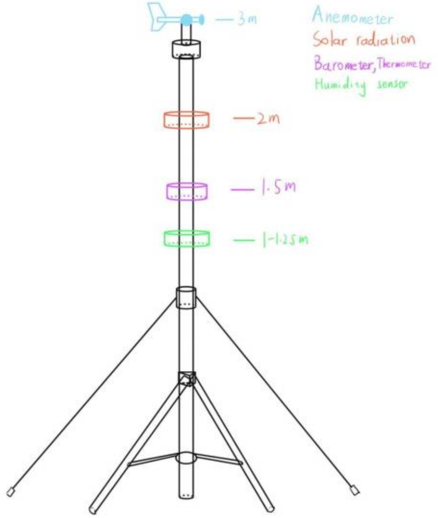
Pugh Chart

Criteria	DATUM (Ian)	Design 1 (Chenxi)	Design 2 (Shutong)	Design 3 (Rowan)
Long Term Data Storage	0	0	-1	1
Increased Data Accuracy	0	1	0	0
Remote Data Access	0	0	1	1
User Friendly	0	-1	0	0
Low Power Requirement	0	1	-1	0
Data Transmission	0	0	1	0
	Totals	1	0	2
	Rank	2	3	1

Decision Matrix - Structure

- Criteria weights and unweighted scores determined through team discussion.
- Winning design was the DATUM with a weighted score of 79.5 out of 100.





		Design DATUM (Rowan)		Design 1 (Chenxi)	
Criteria	Weights	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Weather Durability	0.2	75	15	75	15
Safety Compliance	0.1	90	9	100	10
Low Maintenance	0.2	90	18	70	14
Easy Installation	0.15	50	7.5	30	4.5
Multiple Windspeed Readings	0.1	100	10	100	10
Measured At Industry Standards	0.25	80	20	60	15
Sum	1	485	79.5	435	68.5

Decision Matrix - Pseudocode

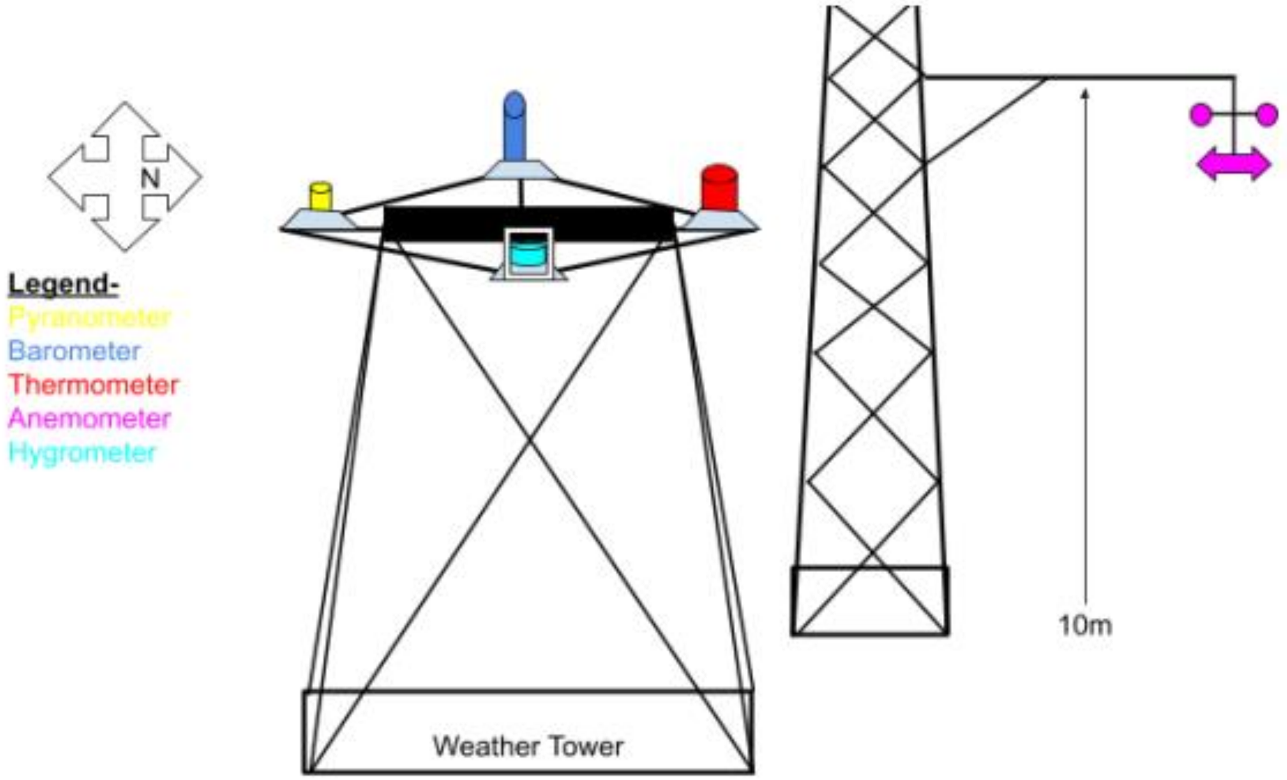
- Criteria weights and unweighted scores determined through team discussion.
- Design 3 scored highest with an 81.25 out of 100, however Design 1 was only 1.5 behind and may be referenced later.

		Dynamic sensor reading frequency based on data stability		Rolling 10-min average w/ hourly database upload	
		Design 1 (Chenxi)		Design 3 (Rowan)	
Criteria	Weights	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Long Term Data Storage	0.25	75	18.75	85	21.25
Increased Data Accuracy	0.25	90	22.5	70	17.5
Remote Data Access	0.25	80	20	90	22.5
User Friendly	0.1	60	6	75	7.5
Low Power Requirement	0.1	80	8	80	8
Data Transmission	0.05	90	4.5	90	4.5
Sum	1	475	79.75	490	81.25

Selected Design - Structure

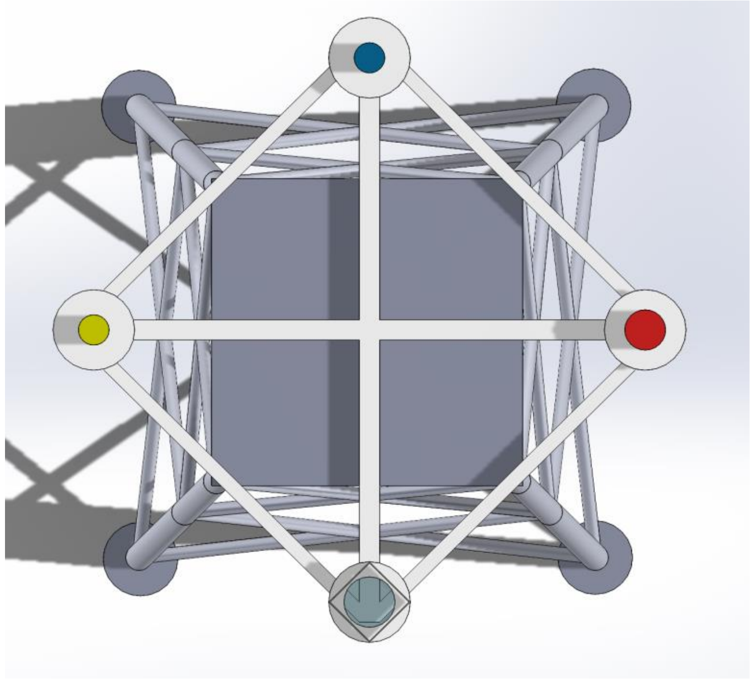
DATUM Design:

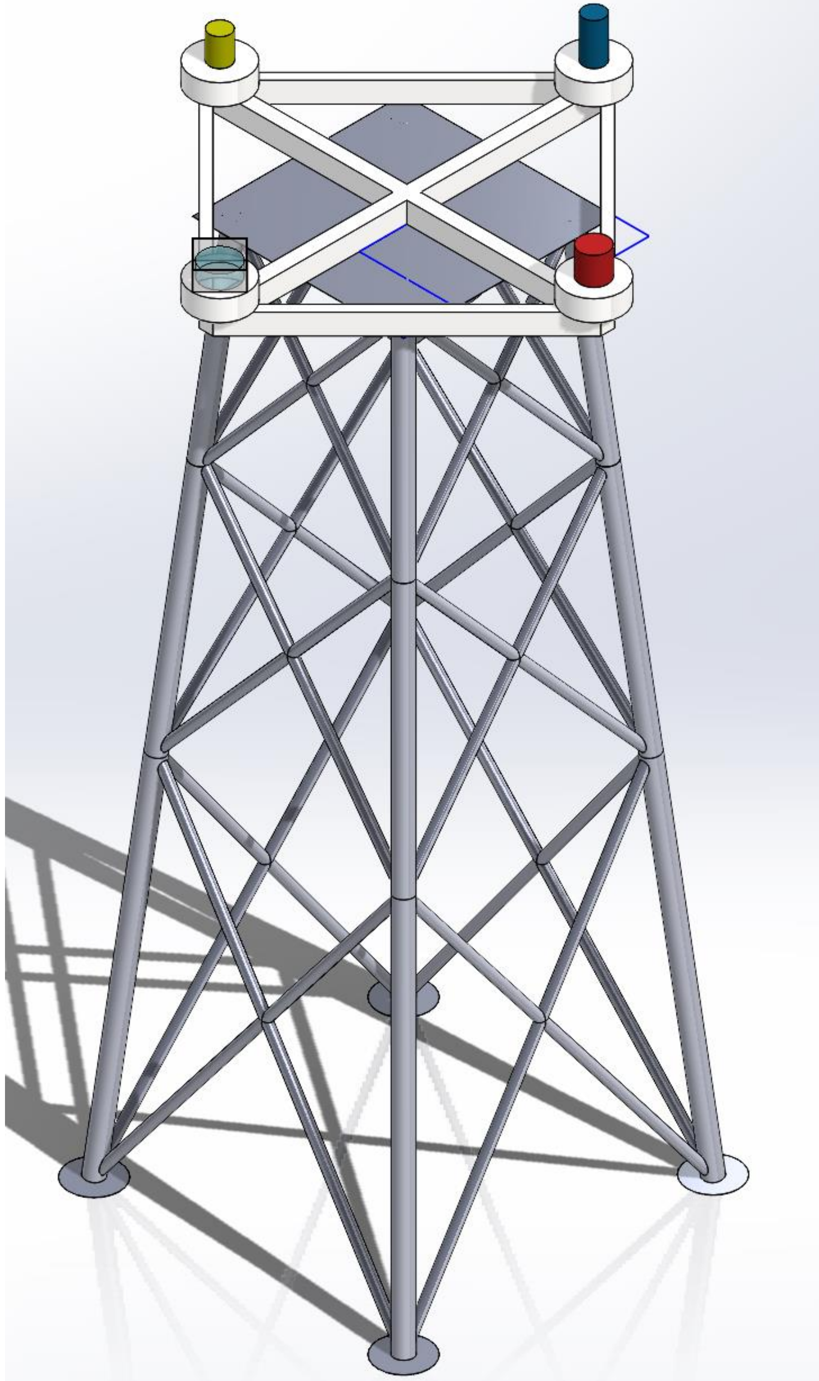
- Utilizes crossbar with sensors mounted on corners.
- Sensor housing can be mounted around any sensors which require it, without causing interference for others
- Anemometer mounted on boom at 10m standard height.



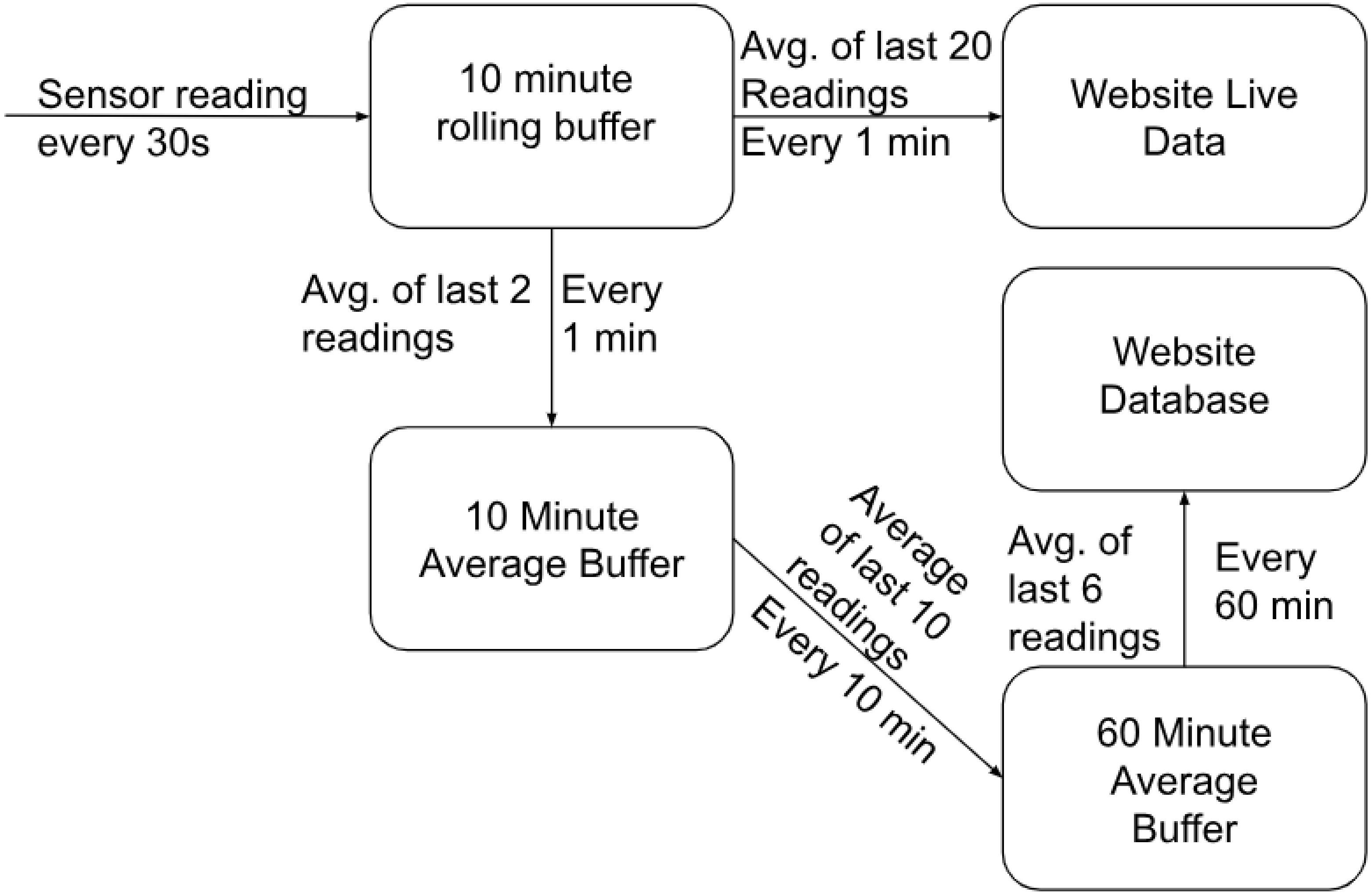
CAD

On the right are the top view and the overall view of our weather station. Our sensors will be deployed on the top of the tower, as shown in the Structure Design. The different colors in the picture represent different sensors. We will also provide shielding covers for sensors if necessary, which is also reflected in the CAD.





Selected Design - Pseudocode



Schedule

Weather Station

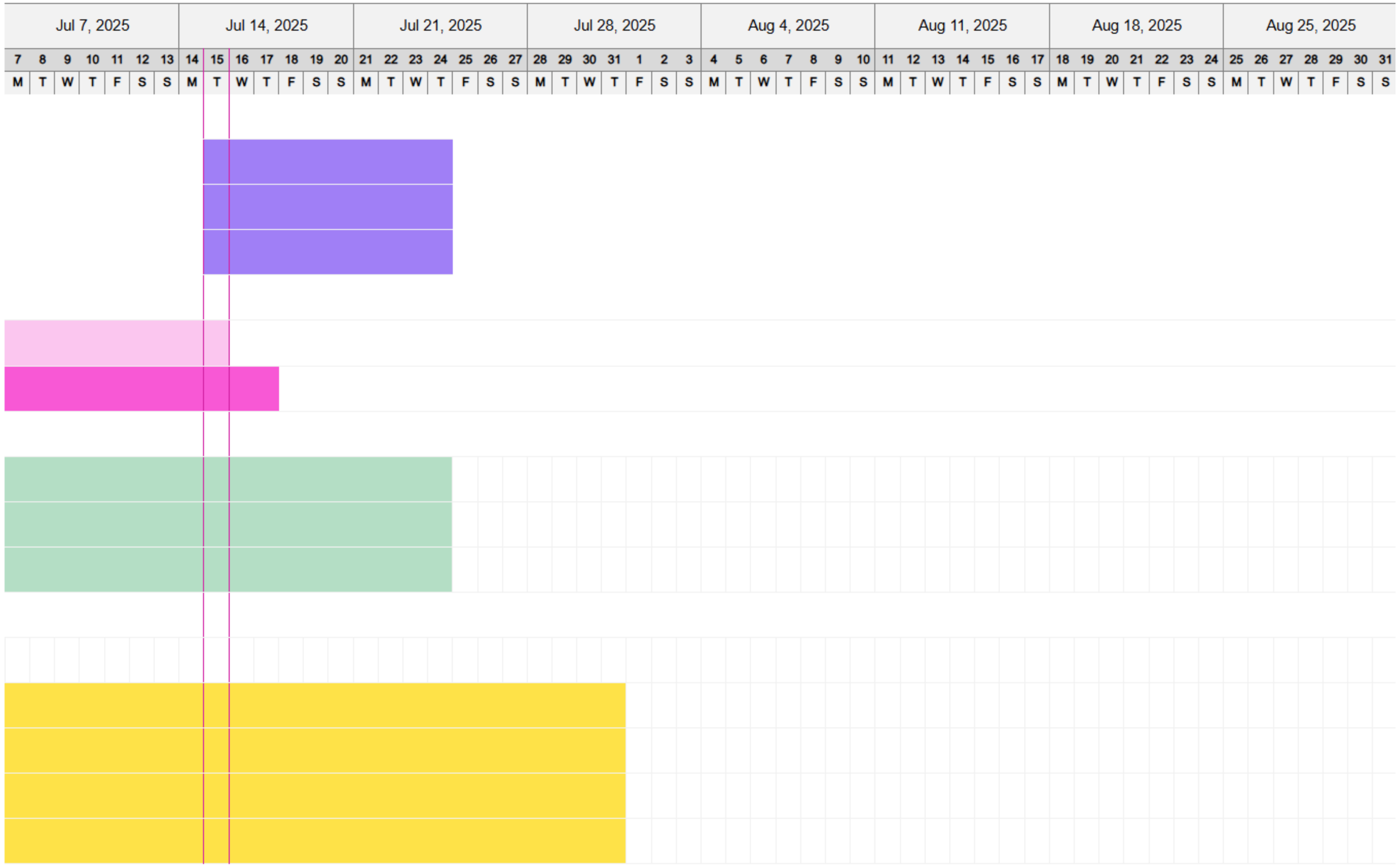
NAU Capstone

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project start: **Tue, 6/10/2025**

Display week: **5**

TASK	ASSIGNED TO	PROGRESS	START	END
Prototype				
Sensor connection	Ian Torp	0%	7/15/25	7/24/25
Calibration Code	Ian Torp & Rowan Mc(	0%	7/15/25	7/24/25
Website Link	Shutong & Chenxi	0%	7/15/25	7/24/25
Report 1 & PRES 2				
Report 1	Everyone	100%	7/3/25	7/15/25
Pres 2	Everyone	45%	6/24/25	7/17/25
Website Check				
Begin Website	Chenxi Dong	0%	6/10/25	7/24/25
Access Website	Everyone	0%	7/1/25	7/24/25
Build	Everyone	0%	7/1/25	7/24/25
Future				
Establish Technical Advisor	Everyone	0%	6/10/25	6/30/25
Track expenses	Rowan B McCullogh	0%	6/10/25	7/31/25
Evaluate progress	Ian Torp	30%	6/10/25	7/31/25
Website	Shutong Wang	0%	6/23/25	7/31/25
CAD design	Chenxi Dong	0%	6/22/25	7/31/25



Budget

~$3000 worth of existing equipment.

Around ~$500 from client for expected additional costs.

Expected $300 contribution from the team.

Potential expenses:

- $5-50 for a replacement micro SD card
- Construction of diamond crossbar for mounting

Fundraising: Incomplete

Current plan: Contact NiuBol for possible sponsorship, Home Depot for crossbar materials.

If still incomplete at end of semester, each member is expected to provide for the team.

Bill of Materials

- Pyranometer - owned
- Barometer - owned
- Thermometer -owned
- Anemometer / Wind Vane -owned
- Humidity Sensor -owned
- Air pressure sensor -owned
- Raspberry Pi -owned
- MicroSD Card - $5-$50
- Cables, brackets, shielding covers, etc. - unknown cost
- Tower - owned
- Crossbar – unknown cost

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Thank You & Questions?