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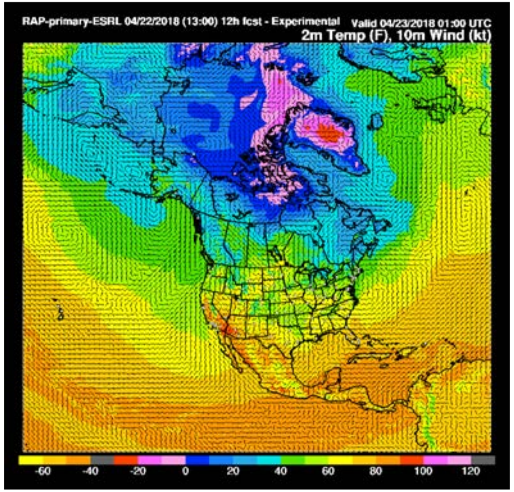
Micro-Weather for Drone Operations



Design Overview

30 April 2018

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Project Mission

Mission: To facilitate drone commercialization, create a UAV-based, automated, micro-weather data collection and flight optimization system to improve safety and reliability of drone flight.

Today, we will focus on:

- Automatically calculating wind speed from a drone.
- Incorporating data from the HRRR forecast model.
- Taking wind speed data and generating an efficient flight path.

Data Mapping and Optimization

Sensors
Gyroscope and GPS

→

Onboard Computer
Wind Velocity Calculation

→

LoRaWAN Node
Long-range communication module

LoRaWAN Gateway
LoRaWAN Home

←

LoRaWAN Cloud

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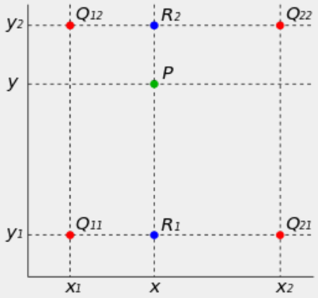
HRRR Model

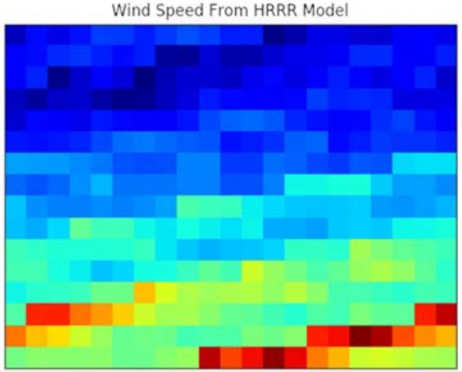
Data Mapping and Grid Creation

- Starts with the HRRR forecast model, provided at 3 km resolution and 15 min updates.
  - Download wind speed at 10 m level
    - The most important variable for drones.
- Bilinear interpolation is used to increase resolution to 0.75 km.
- Process creates placeholders for future wind speed updates:
  - Secondary flight optimization
  - Forecast models

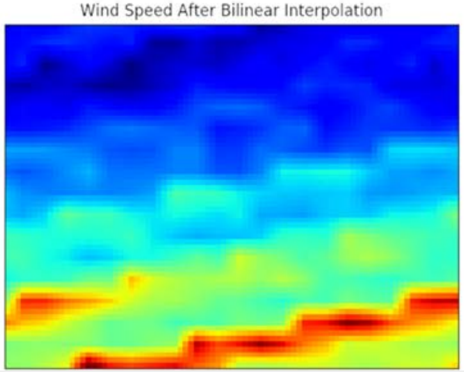


$$f(x, y_1) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21})$$
$$f(x, y_2) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22})$$

$$f(x, y) \approx \frac{y_2 - y}{y_2 - y_1} f(x, y_1) + \frac{y - y_1}{y_2 - y_1} f(x, y_2)$$

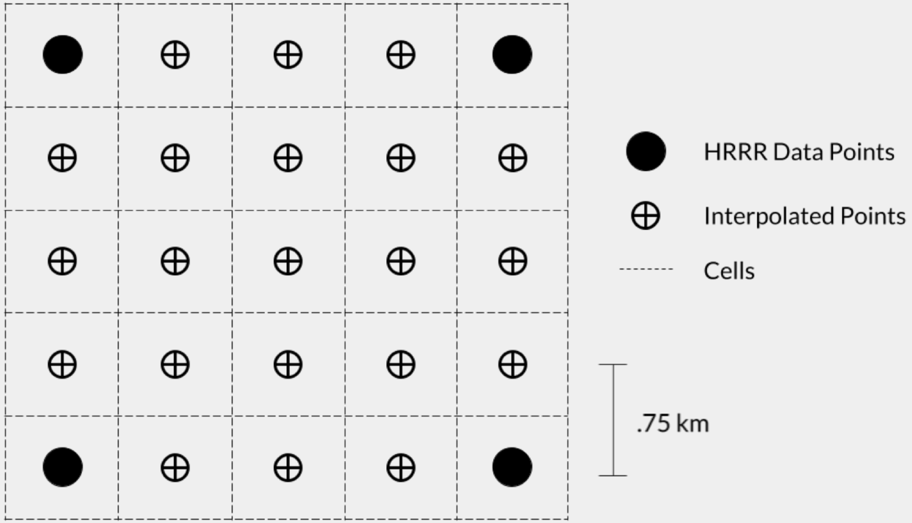


Grid size: 3 km * 3 km



Grid size: 0.75 km * 0.75 km

Route Discretization

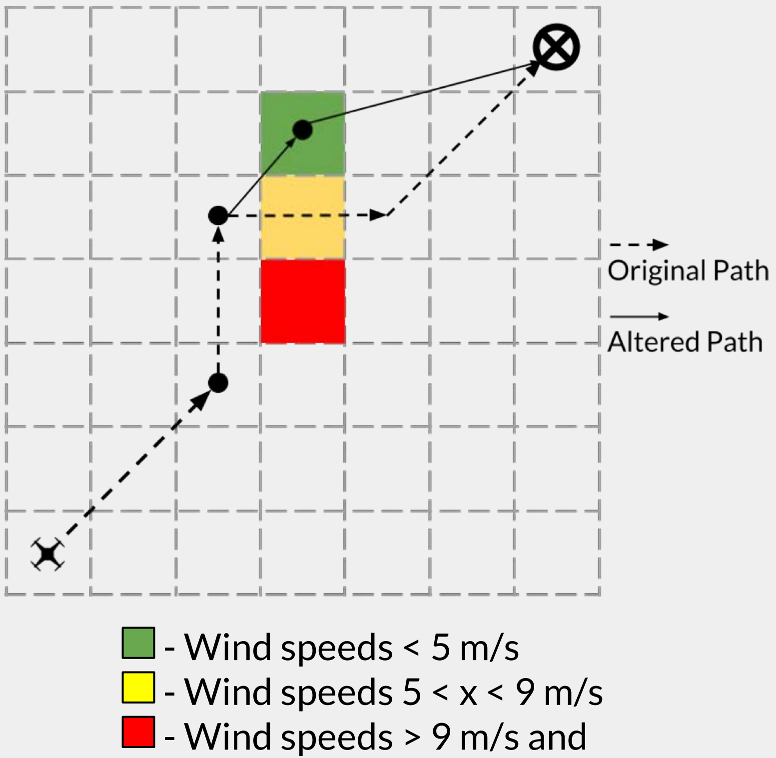


Possible waypoints are created at the interpolated points.

- This allows for first flight path to be generated.
- Saves locations where wind speed information is updated.

Preliminary Flight Optimization

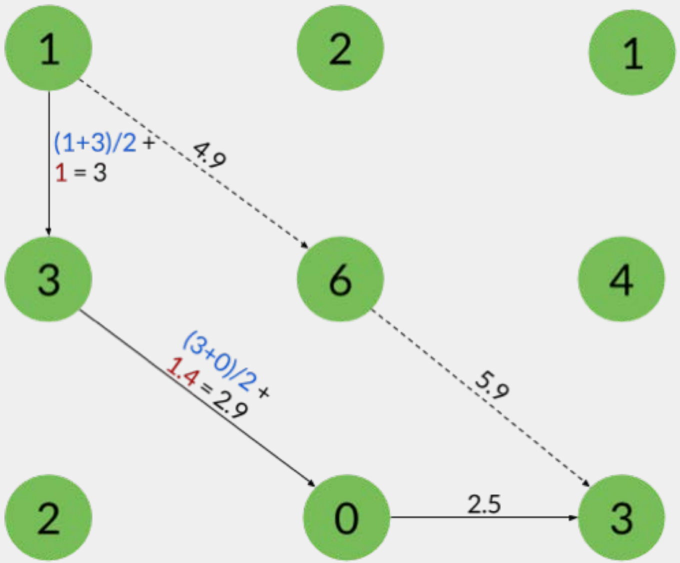
- Done before drone flight.
- Using only HRRR model data to create a map.
- Diverts around no-fly zones (weather or FAA) and avoiding yellow zones.
- Optimized route travels along discretized waypoints.



Dijkstra’s Algorithm

- A common method for finding the optimal path between two points.
- The weight for each route is calculated based on:
  - Total distance
  - Average wind speed
- Weighting the variables above also optimizes for the secondary variables such as time and battery life.

Numbers in circles represent wind speeds, in m/s.

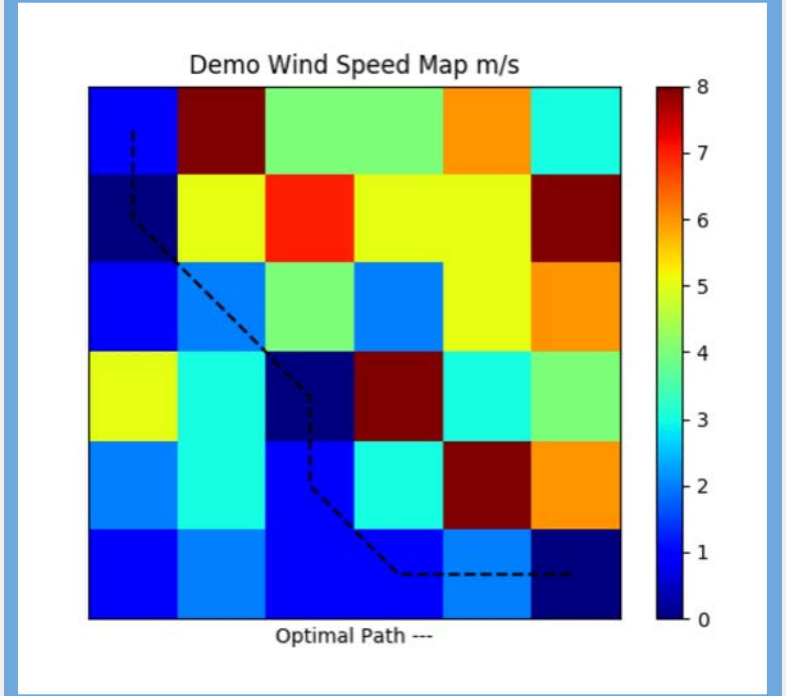


Weighted Distance Comparison

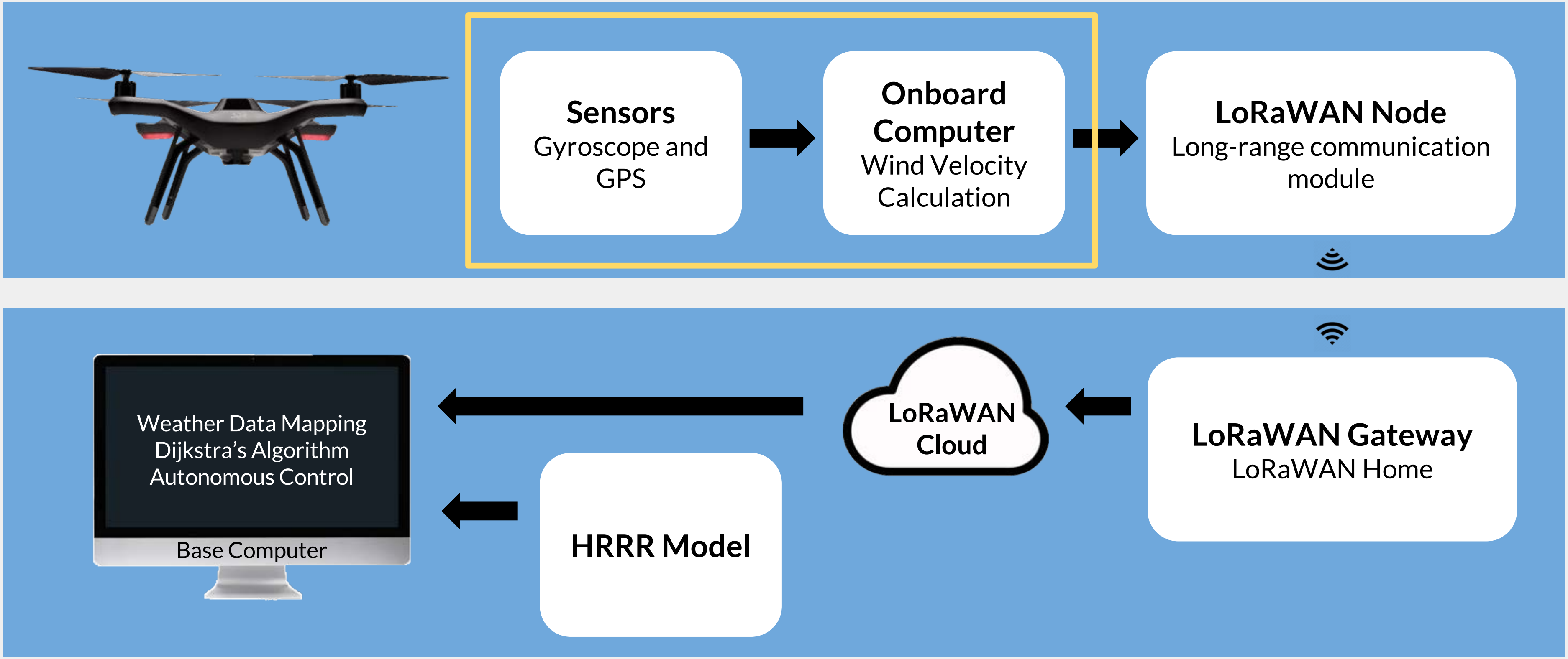
Original Path : 4.9 + 5.9 = **10.8**
Optimal Path : 3+2.9+2.5 = **8.4**

Secondary Flight Optimization

- Update the wind speed map. (0.75 km * 0.75 km) using data from the previous drones
- Find the optimal path using the updated map



Velocity Calculation



Indirect Wind Speed Measurement

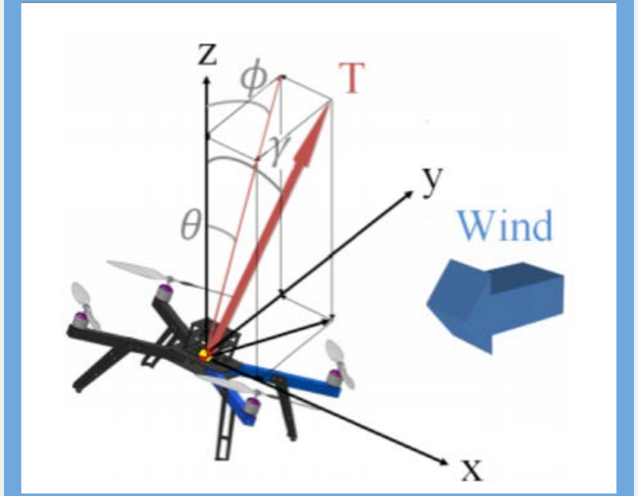
- Calculate the tilt angle (γ) using pitch (ϑ) and roll ($\emptyset$) angles from the gyroscope and accelerometer sensor.
- Calculate the total wind speed as a function of:
  - ρ – Air density
  - $D(\gamma)$ – Drag force
  - C_D – Drag coefficient
  - $A(\gamma)$ – Cross-sectional area

$$A(\gamma) = [Area_{Front} * |Cos(WindDirection)| * |Cos(\gamma)|] + [Area_{Side} * |Sin(\gamma)|] + [4 * (0.157)^2 * \pi * Sin(\gamma)]$$

$$\gamma = cos^{-1}\left(\frac{\vec{n}_{xy} \cdot (\vec{e}_{\emptyset} \times \vec{e}_{\theta})}{|\vec{n}_{xy}| \cdot |\vec{e}_{\emptyset} \times \vec{e}_{\theta}|}\right)$$

$$D_{simple} = mgtan(\gamma)$$

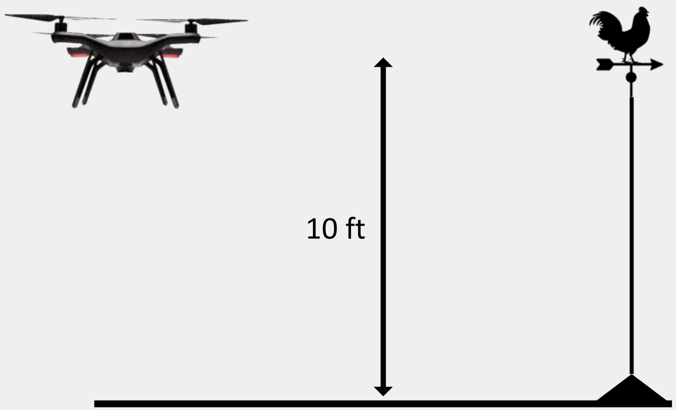
$$v = \sqrt{\frac{2 * D(\gamma)}{\rho * A(\gamma) * C_D}}$$

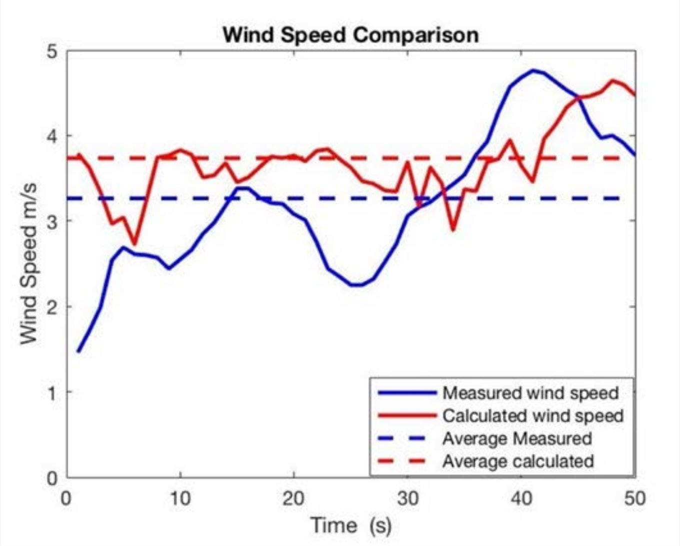


Moyano Cano, Javier, et al. "Quadrotor UAV for wind profile characterization." University of Madrid, 2013.

Test Method

- Measure and calculate wind speed at the same time, height, and general area.
- 60–second trials.





Testing Results

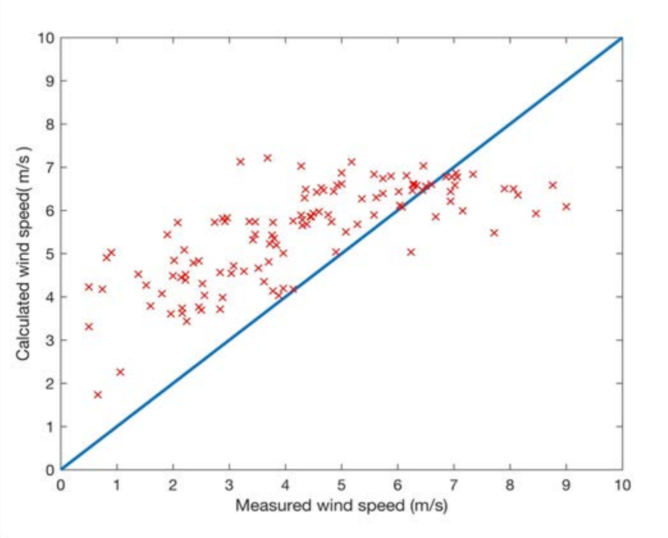


Figure 1: Comparison between calculated and measured wind speed for test 5.

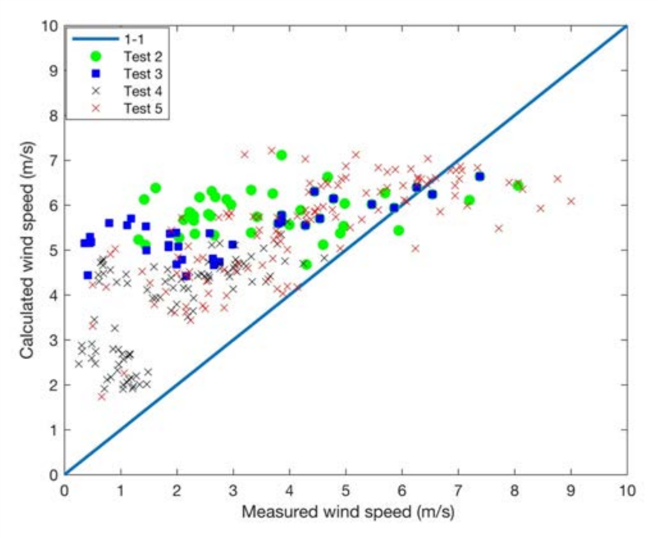


Figure 2: Comparison between calculated and measured wind speed for all tests.

Source of Errors

- Didn't account for wind direction in the first 4 tests.
- The drone takes time to return to equilibrium after a wind disturbance.
- Using one microcontroller with multiple chips slows the transition of the gyroscope data.
- Cross-sectional area formula.

Test 5 Results

Trial	Mean calculated wind speed (m/s)	Maximum calculated wins speed (m/s)	Minimum calculated wins speed (m/s)	Mean Measured wind speed (m/s)	Relative Error	Error (%)
1	6.25	6.86	5.72	4.11	0.52	52%
2	4.37	4.80	4.03	2.76	0.58	58%
3	5.49	6.21	4.52	5.20	0.05	5%
4	1.34	2.82	1.73	1.66	0.18	18%
5	5.84	6.07	5.67	4.71	0.24	24%
6	5.03	5.50	4.30	3.39	0.48	48%
7	6.90	7.21	6.58	5.57	0.23	23%
8	3.88	4.59	3.43	2.69	0.44	44%
9	6.38	6.58	5.85	6.91	0.07	7%
10	6.40	6.86	5.00	6.00	0.06	6%

Future Improvements

Next steps:

- More sophisticated velocity calculation.
- Altitude analysis.
- Quicker data transmission.

Questions?