PRINCETON UNIVERSITY

IRoM Lab
Intelligent Robot Motion Lab

FlowDrone: Wind Estimation and Gust Rejection on UAVs Using Fast-Response Hot-Wire Flow Sensors

Nathaniel Simon Allen Z. Ren Alexander Piqué David Snyder Daphne Barretto
Marcus Hultmark Anirudha Majumdar

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Motivation

Multirotor UAVs must be able to operate in extreme wind conditions. Modern multirotor UAVs do not directly sense wind due to limitations in the available sensors.

Hypothesis: Sensing wind *directly* will improve performance in wind.

FlowDrone: A UAV with MAST (top right --- an omnidirectional flow sensor) and wind-aware control.

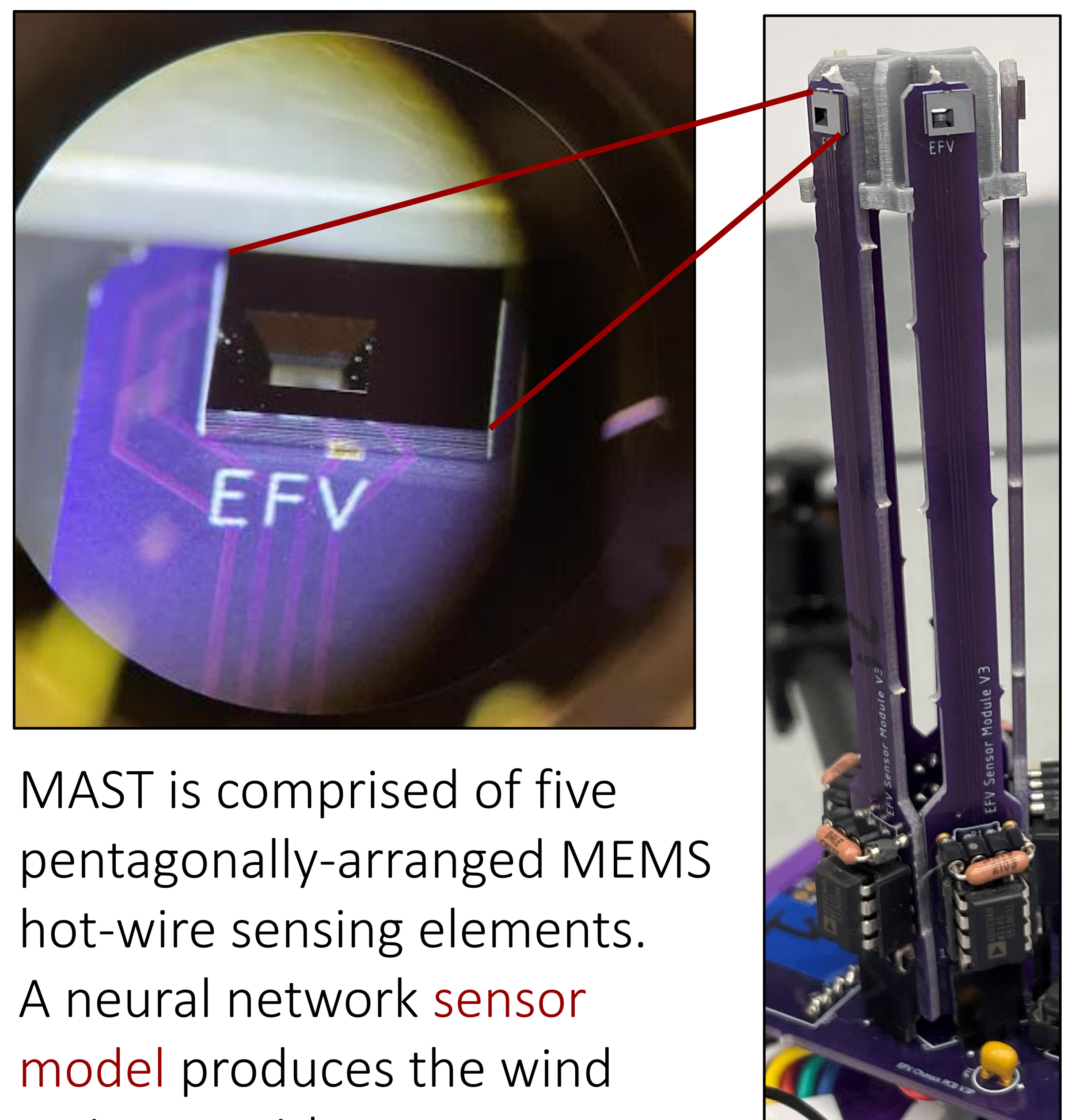
Background

Conventional anemometry techniques (e.g. pitot-static tubes, hot-wires, ultrasonic) are too slow, insensitive, or bulky for omnidirectional flow sensing.
Custom sensors show promise, but limited accuracy or unreported bandwidth:

- Whisker-like [Tagliabue et al. '20]
- Pressure-based [Yeo et al. '15], [Bruschi et al. '16], [Prudden et al. '17]

Wind Sensing

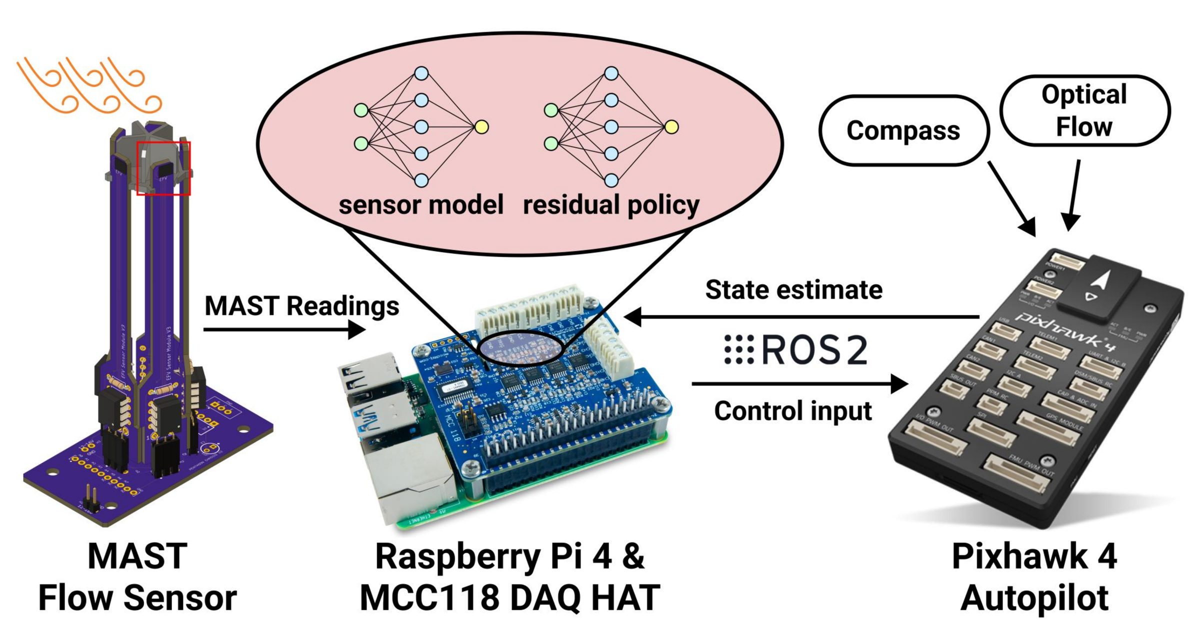
In prior work [Simon et al. '22], we develop MAST (MEMS Anemometry Sensing Tower), a lightweight, fast, and accurate omnidirectional flow sensor.



MAST is comprised of five pentagonally-arranged MEMS hot-wire sensing elements. A neural network sensor model produces the wind estimate with accuracy:

Estimate	Average Error	95% Confidence
Angle (0°-360°)	1.6°	5.0°
Speed (0.0-5.0 m/s)	0.14 m/s	0.36 m/s

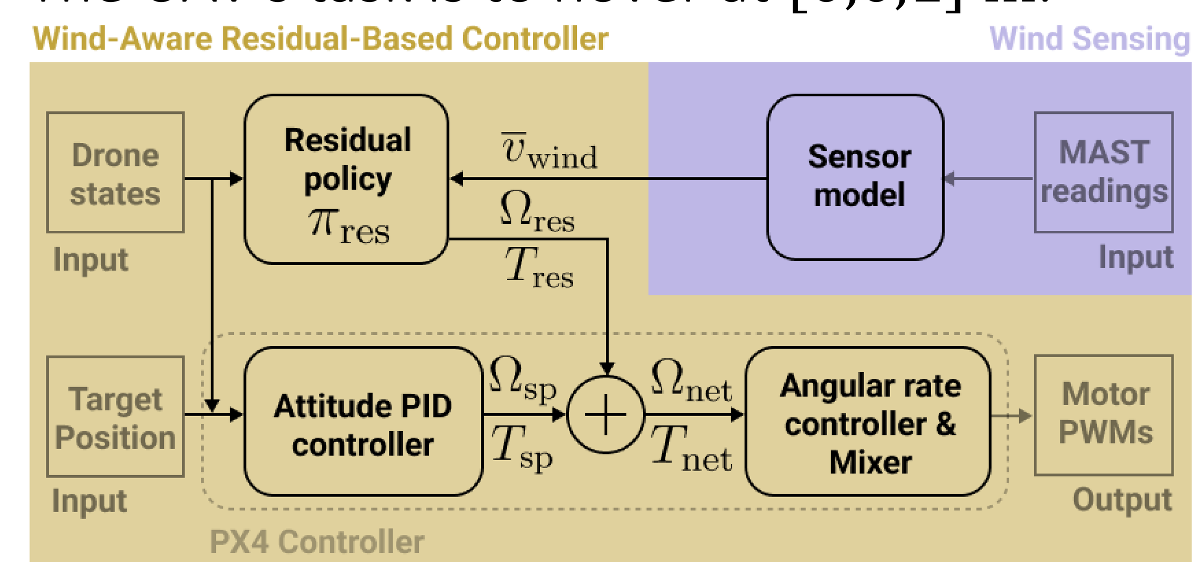
System Overview



FlowDrone runs the sensor model and wind-aware residual-based controller with onboard computation and sensing.

Wind-Aware Control

We train the residual-based policy using Soft Actor Critic [Haarnoja et al. '18] in `gym-pybullet-drones` [Panerati et al. '21], simulating drag forces [Craig et al. '20] based on gust profiles measured in-flight. The UAV's task is to hover at [0,0,1] m.

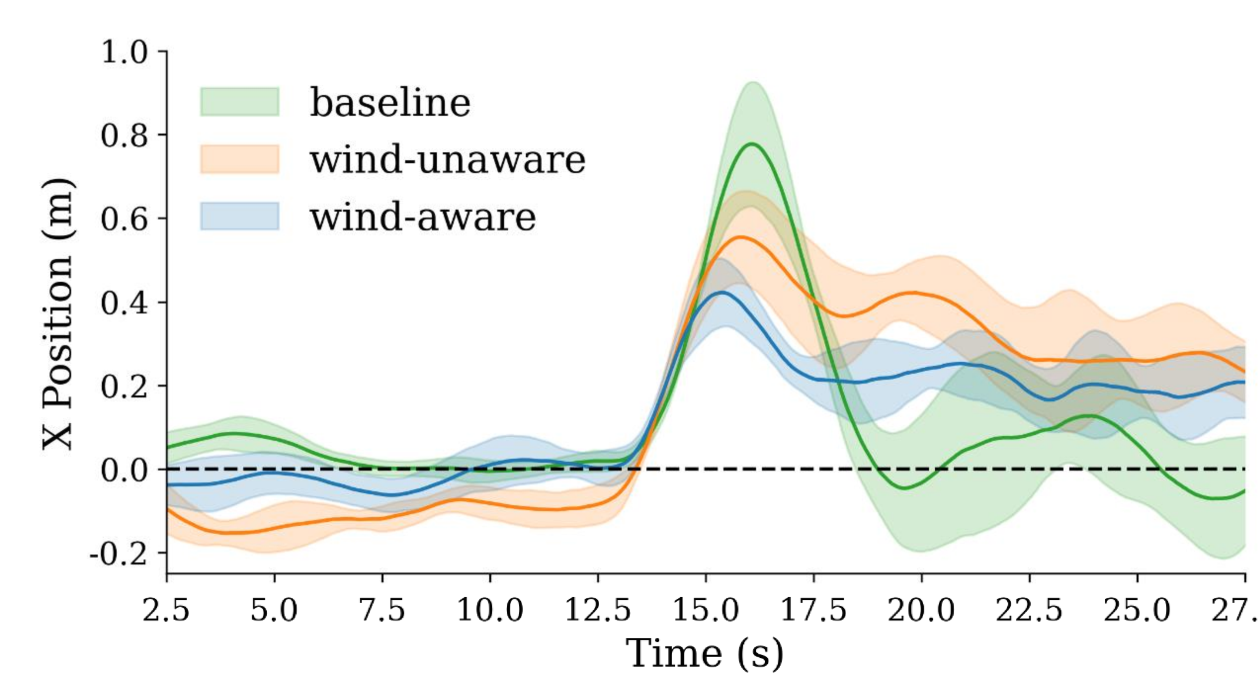


Results

We compare the performance of the following

- **Wind-Aware Residual-Based Controller ("wind-aware").** (As in the previous figure.)
- **Wind-Unaware Residual-Based Controller ("wind-unaware").** Same architecture as wind-aware but trained without access to a wind estimate.
- **PX4 Attitude Controller ("baseline").** Open-source PX4 Autopilot for attitude control.

We conducted 10 flights for each controller in controlled gust conditions. The average performance of each controller is:

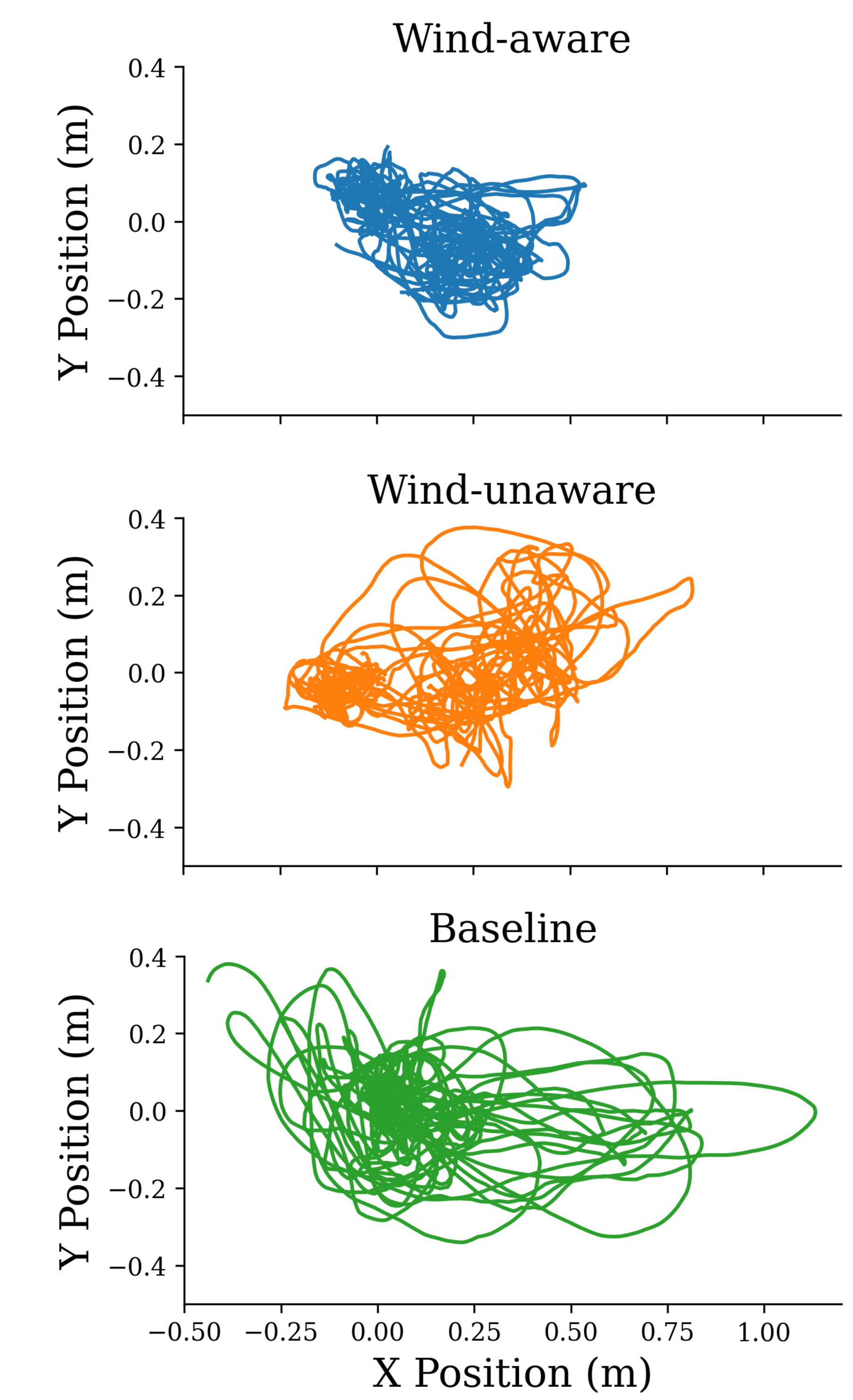


Results cont.

Evaluation metrics for all 30 flights with standard deviations in parentheses:

	Wind-aware	Wind-unaware	Baseline
Max Error (m)	**0.441** (0.064)	0.582 (0.094)	0.780 (0.142)
MSE (m^2)	**0.035** (0.006)	0.079 (0.013)	0.057 (0.016)
Range (m)	**0.538** (0.072)	0.773 (0.100)	0.962 (0.222)

For each metric, wind-aware outperforms the others. Plotting all flight trajectories:



These results demonstrate a significant improvement with wind-aware control and the benefit of direct wind measurement.

Future Work

- Varying wind *direction* in simulation and during evaluation.
- Outdoor testing in real winds.
- On-line learning to fine-tune the wind-aware controller in hardware.