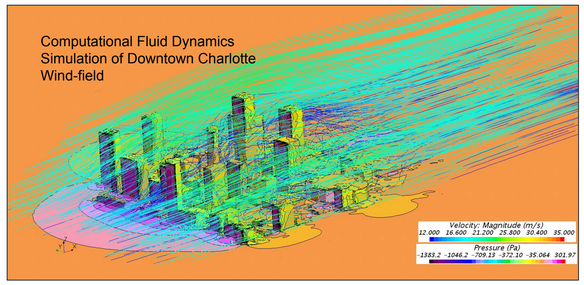
Vision-Based Ping-Pong Ball Anemometer

Cedric Davis (Faculty Advisor: Dr. Artur Wolek)
Mechanical Engineering and Engineering Science, UNC Charlotte

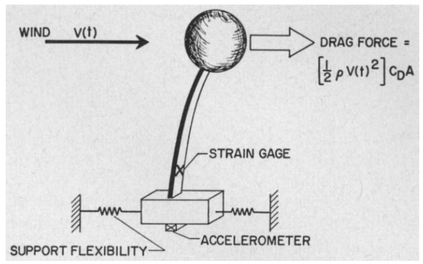
Presented at the 2024 UNC Charlotte Undergraduate Research Conference (URC)

Introduction

- Uncrewed aerial vehicles (UAVs) are influenced by wind conditions that can hamper their operations. and may perform erratically and endanger the environment.



- Measuring the wind in areas where UAV's operate can be helpful in deterring catastrophic events.
- Our work takes inspiration from the design of "drag spheres" that are ground-based systems.



Reed III, Wilmer H., and James W. Lynch. "A Simple fast response anemometer." *Journal of Applied Meteorology* (1963): 412-416.

Objective

- Develop a vision-based "ping-pong anemometer" to later use on a UAV (quadrotor) to estimate wind speed using cost-effective means.

Dynamic Model for Wind Inference

- A 3D spherical pendulum model was developed to represent motion in the presence of wind drag

Equations of motion

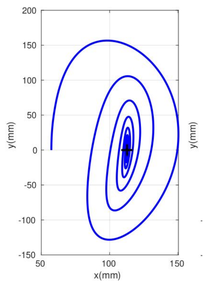
$$\begin{aligned} \boldsymbol{e}_r &: m(-L\dot{\theta}^2\sin^2\phi - L\ddot{\phi}) = -T - mg\cos\phi + D_r \\ \boldsymbol{e}_\theta &: m(L\ddot{\theta}\sin\phi + 2L\dot{\theta}\dot{\phi}\cos\phi) = D_\theta \\ \boldsymbol{e}_\phi &: m(L\ddot{\phi} - L\dot{\theta}^2\sin\phi\cos\phi) = mg\sin\phi + D_\phi \end{aligned}$$

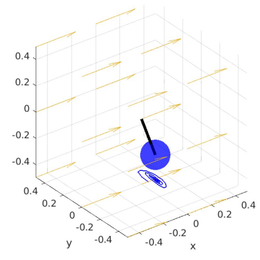
Drag Model

$$\boldsymbol{D} = -\frac{1}{2}\rho S C_D ||\boldsymbol{v}_{\text{rel}}||^2 \hat{\boldsymbol{v}}_{\text{rel}}$$

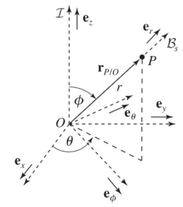
Horizontal Wind $\boldsymbol{\delta} = w_x\boldsymbol{i} + w_y\boldsymbol{j}$

Flow-relative Velocity $\boldsymbol{v}_{\text{rel}} = \boldsymbol{v} - \boldsymbol{\delta}$





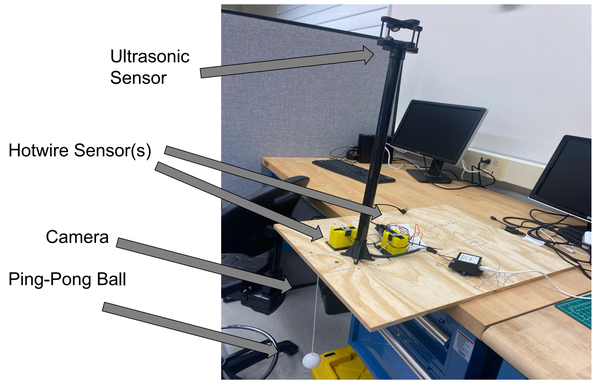
Spherical coordinate system
Image Source: Kasdin and Paley (2011)



- The model can be used to infer the wind speed based on position values derived from imaging.

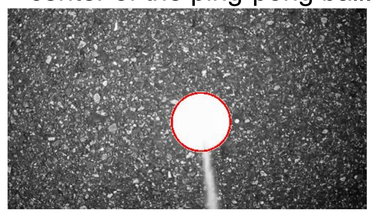
Data Collection Methodology

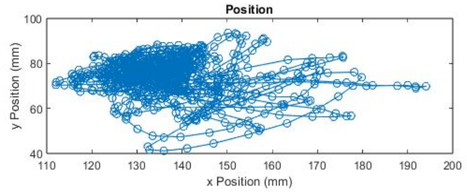
- A ping-pong ball was suspended a predetermined distance from the base of a board, with a camera pointed on top of the ball
- The board also mounted inexpensive hotwire sensor (Modern Devices) and an expensive ultrasonic sensor (Trisonica Mini) for data comparison.
- Images and sensor data were recorded in an outdoor experiment and then post-processed in MATLAB.



Results

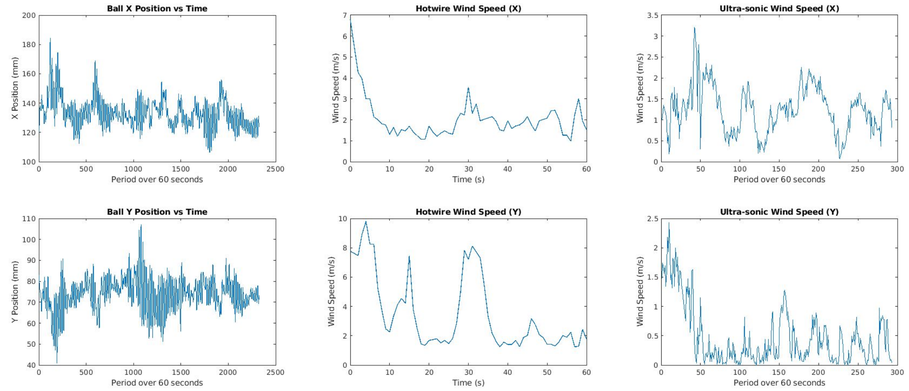
- We used a circle detection algorithm in MATLAB to find the position of the center of the ping-pong ball.





Left: Example image from data recording, Right: X-Y ball position data gathered from image processing

- We are not yet using the pendulum model; however, trends in the displaced pixel ball are observed when comparing with other sensors.



Data collected for the three sensors used on the board. Represents 60 seconds of data for each sensors. Some sensors collect data at high frequencies, hence the disparity in data densities.

Discussion

- The ultrasonic wind speed data exhibits higher precision compared to other methods.
- The X-Y data collected by the vision processing model can be converted into wind estimates based on drag models and the pendulum-like movement of the measurement setup

Conclusion and Future Work

- A prototype ping-pong ball anemometer was developed and data was recorded comparing to existing anemometers.
- In future research, we aim to deploy this system on a UAV. We suspect that rotor wake will interfere with the wind speed, so we will need to determine a distance away from the quad that would alleviate that interference but not cause image resolution issues.

Acknowledgements: We thank Nick Kakavitsas for his mentorship and assistance with developing the code.