Estimating Wind Speeds with Visual Anemometry

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Abstract

Wildfires continue to be a significant problem due to the release of carbon dioxide and other pollutants in the atmosphere, which contributes to global warming. Our ability to analyze wind speed and direction is crucial in combating these natural disasters. Deploying physical anemometers in large forests to measure wind speed is prohibitively expensive both financially and practically. Wind is not visible to the naked eye, but it can be observed though the movement of vegetation, such as canopies. We can take advantage of these visual cues to make estimates of wind speed and direction. With a single camera, we detect canopy in the field of view using YOLOv3, and estimate the canopy kinematics using estimateFlow. We present the relationship between the vegetation and the kinematics of two trees and the wind speed the trees were exposed to. Our presented method can assist firefighters in preventing the spread of wildfires.

Introduction

What is Visual Anemometry?

- Many major problems in the world revolve around the wind, including the issues of air pollution, climate change, and wildfires.
- Scientists take advantage of small handheld anemometers to calculate wind speeds, but it is often impractical.
- Our eyes are capable of making quick, rough estimates of direction and speed of moving objects.
- Extending this ability to a broader scale, visual anemometry determines local wind conditions based on the observed interactions between the wind and structures in the environment.
- These methods aim to extract wind-related information from visual cues provided by objects in the environment.

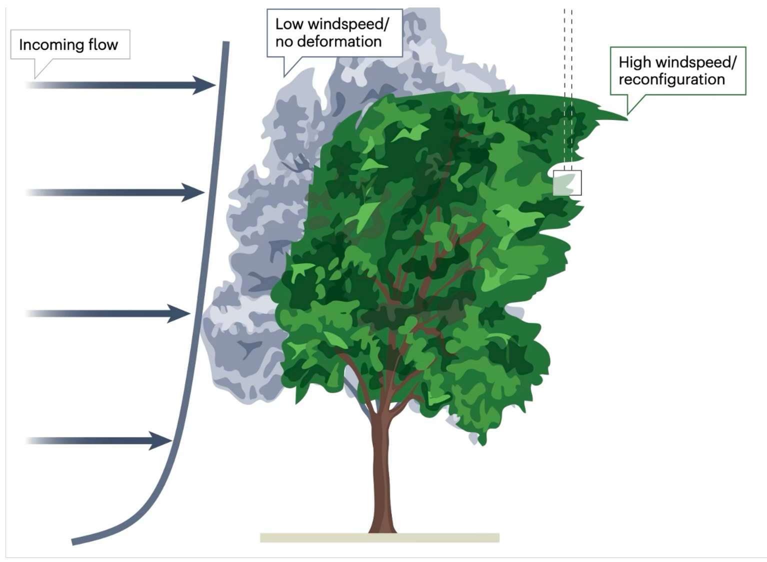

Image adapted from: Dabiri et al. 2023

Methodology

YOLOv3 → estimateFlow

Our methodology centers around two main algorithms: YOLOv3 and estimateFlow.

- YOLOv3 is a machine learning algorithm that takes advantage of a convolutional neural network to detect objects. In this project, YOLOv3 is primarily used to isolate the images of trees from the background noise.
- estimateFlow is an algorithm that calculates the optical flow (apparent velocities) across video frames. In this project, estimateFlow is mainly used to collect data on velocity vectors on different parts of the trees.

After applying both methods, we analyze our data to draw conclusions and identify trends that can help us predict wind speed and direction.

Methodology Cont.

YOLOv3:

- YOLOv3 is an object detection algorithm.
- Uses bounded boxes to define the object.
- Development set consisted of camphor and oak tree samples (915 frames).
- Accuracy precision of the object detection is 95.375%.

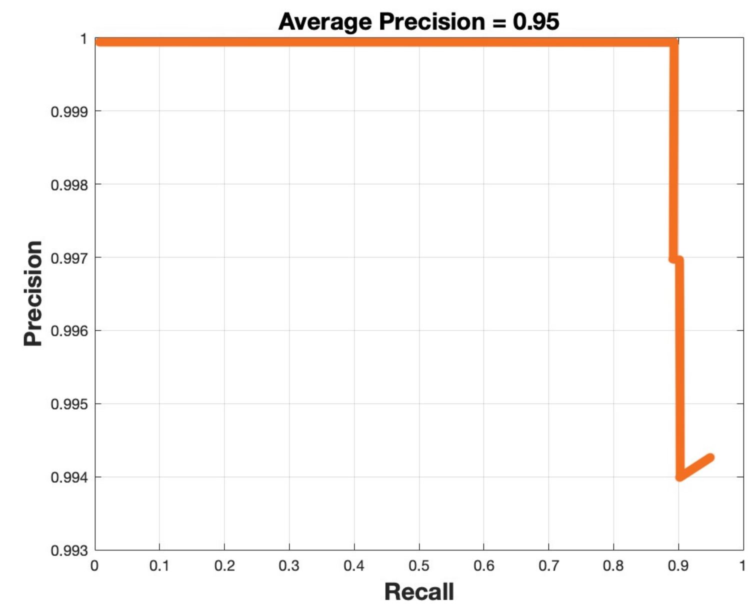

Figure 1: Precision-Recall Curve

Figure 2 : Example Training Data

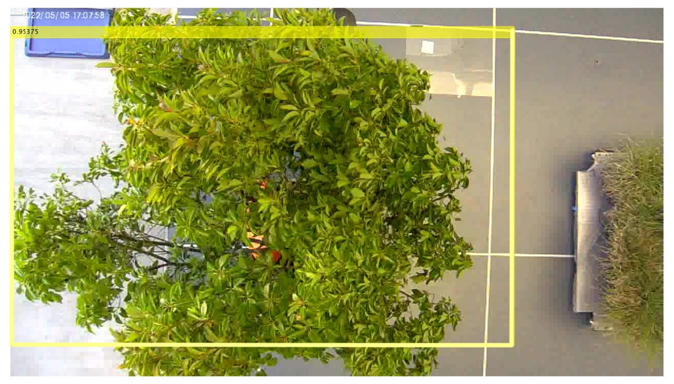

Figure 3: YOLOv3 Prediction Example

estimateFlow:

- EstimateFlow is an optical flow algorithm.
- Calculates velocity vectors over consecutive video frames.
- Splits data into both horizontal and vertical velocity components at each pixel.
- Allows for both a qualitative and quantitative approach to data analysis.

Results

A Qualitative View on Data:

- Branch movement increases further away from the tree trunk.
- A sense of directionality can be gained, especially at higher speeds.

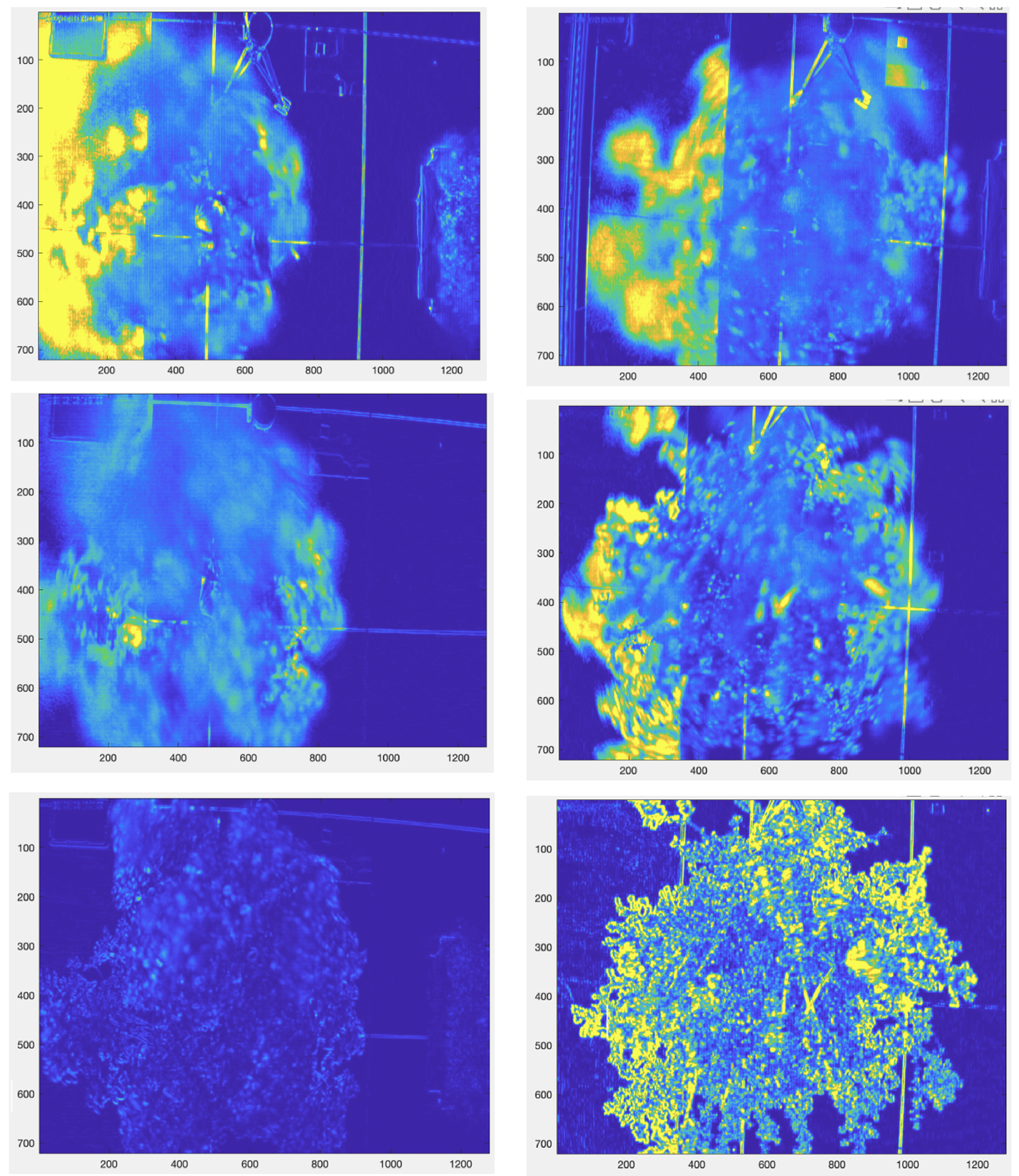

Figure 4: Camphor Tree (Left Column). Oak Tree (Right Column). From top to bottom rows: High, Medium, Low Speeds. Brighter color represents greater displacement.

Results Cont.

A Quantitative View on Data:

- We identify a relationship between the wind standard deviation and the canopy displacement standard deviation.
- Relationship breaks down at low wind speeds perhaps due to low signal to noise ratio.

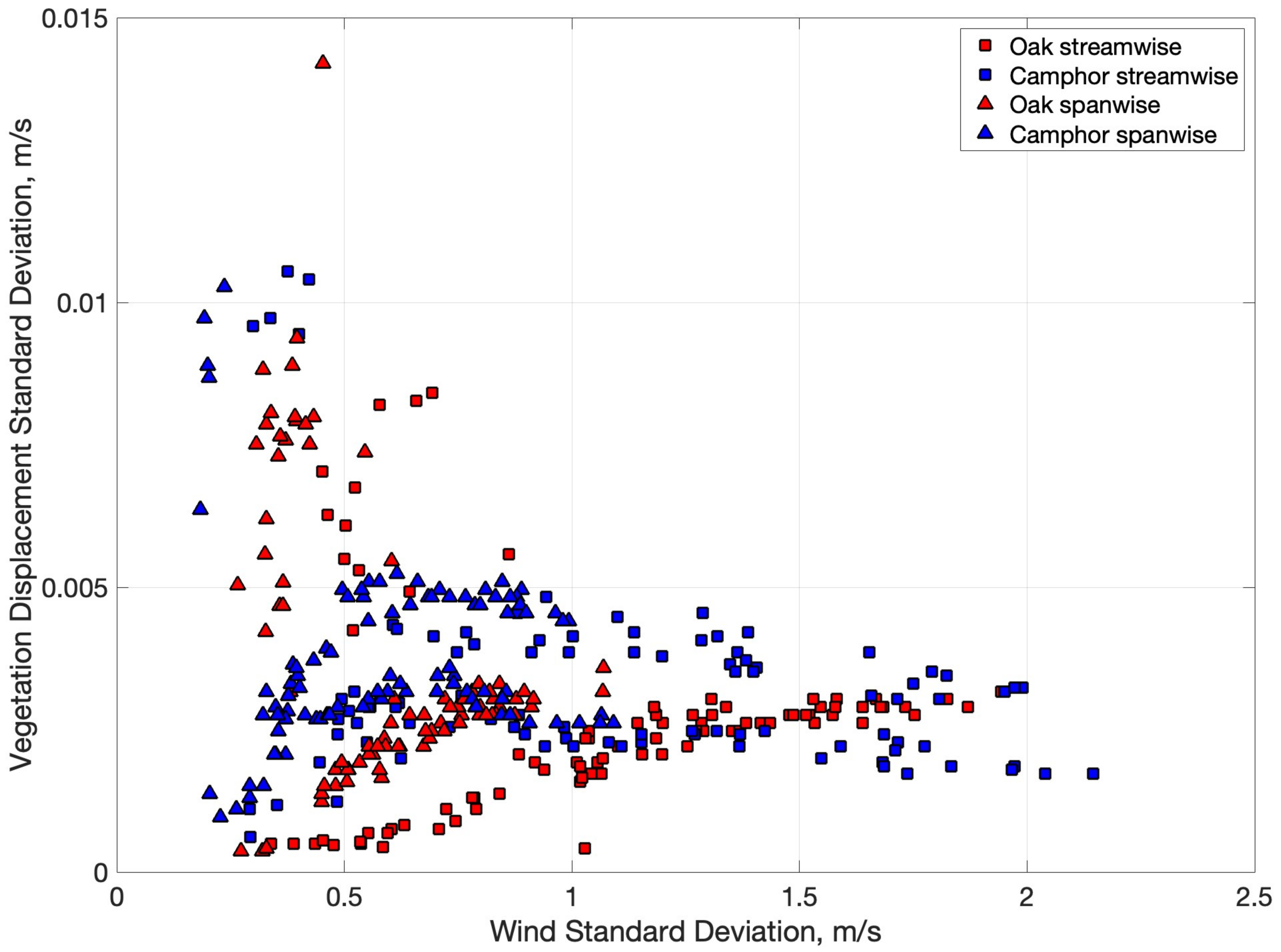

Figure 5: Identified relationship between wind speed and vegetation displacement fields for each component separately.

Conclusions

Visual Anemometry is a set of measurement techniques used to estimate wind speeds with visual cues of the environment. The current state of the method requires an anemometer as a reference point for calibration. Current state of the method is unreliable for low wind speeds.

Future work:

- Improve accuracy in isolating vegetation and reducing background noise.
- Reducing code runtime.
- Extend analysis to a 3-dimensional plane to improve model predicion at low speeds.
- Consider material strength and structure as factors contributing to wind speed and direction.
- Extend analysis to other types of vegetation such as bushes and grass.

Additional impacts of our method:

- Help develop more efficient solar and wind farms.
- Manage windflow in built environments.
- Monitor environmental phenomena such as air pollution.
- Track and improve weather and climate models.

References

Dabiri, J.O., Howland, M.F., Fu, M.K., and Goldshmid R.H. Visual anemometry for physics-informed inference of wind. Nat Rev Phys (2023). https://doi.org/10.1038/s42254-023-00626-8