Predicting Vineyard Mildew with UAV Remote Sensing and Machine Learning

Jonathan Peña, Department of Computer Science

Research Partners: Michel Acosta, Ardavan Sherafat

Mentors: Dr. Amar Raheja, Dr. Subodh Bhandari

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Introduction

Vineyard mildew poses a significant threat to wine production, affecting both yield and quality, and represents a persistent challenge for viticulturists worldwide. Traditional methods of mildew management often rely on regular applications of fungicides, a practice that is both cost-intensive and environmentally detrimental. Furthermore, the evolving dynamics of climate change and the growing scarcity of labor resources necessitate the exploration of innovative, sustainable, and efficient approaches to vineyard management. This study capitalizes on the advancements in unmanned aerial vehicle (UAV) technology and machine learning to pioneer an approach for the early detection and prediction of vineyard mildew. By utilizing UAVs equipped with multispectral and hyperspectral sensors, our research captures critical vine health indicators in real-time. These indicators, when analyzed through machine learning models, enable the anticipation of mildew outbreaks before they become visually apparent, thereby facilitating timely and targeted interventions. The integration of UAV remote sensing and machine learning in this context not only represents a technological leap forward but also aligns with the pressing need for sustainable agricultural practices. By reducing the reliance on fungicides, this approach minimizes environmental impact, lowers operational costs, and enhances the resilience of vineyards to the adversities posed by climate change and labor shortages. This introduction sets the stage for a detailed exploration of our methodology, findings, and their implications for the future of vineyard management and precision agriculture at large.

Objectives

- To create and refine machine learning algorithms that can accurately predict the risk of mildew outbreaks in vineyards by analyzing data derived from multispectral and hyperspectral imagery.
- To utilize the predictive capabilities of our model to inform a more targeted and efficient use of fungicides, thereby reducing environmental impact and lowering operational costs for vineyard management.

Materials

UAVs: DJI Matrice 600, Lancaster UAV from Precision Hawk, and Aibot X6 Multicopter.

Remote Sensors: Nano Hyperspectral Sensor, Tetracam ADC Lite Multispectral Sensor, and RedEdge Multispectral Sensor by MicaSense

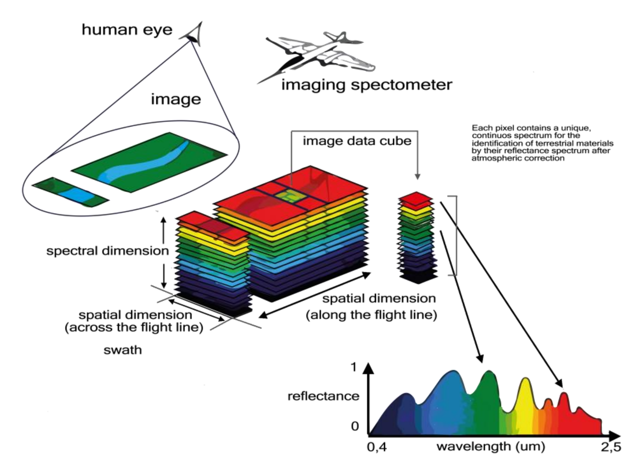
Handheld Sensors: SPAD 502 Chlorophyll Meter, HS2 Handheld Spectroradiometer, and WPC4 Water Potential Meter

Software: Headwall's Agview, HyperSpec III, and SpectralView and LabelImg

Machine Learning Models: Linear Regression and Neural Networks

Methodology

Our study utilized the vineyard fields located at the intersection of Temple Ave and Campus Drive at Cal Poly Pomona, with the research spanning the entire vineyard growing season starting in February. We employed Unmanned Aerial Vehicles (UAVs) equipped with remote sensing cameras to capture hyperspectral and multispectral images of the fields. Hyperspectral and multispectral imaging technologies represent advanced methods for capturing and analyzing data across the electromagnetic spectrum. While traditional photography captures images in just three broad bands (red, green, and blue), multispectral imaging expands this capability by dividing the spectrum into several broad bands. Hyperspectral imaging takes this further by splitting the spectrum into hundreds of narrow bands, each corresponding to a specific wavelength of light. This granularity provides a unique spectral signature for every pixel, enabling precise identification and analysis of various materials and conditions on the Earth's surface. Such detailed spectral information is invaluable for applications requiring fine filtering between different objects, materials, and processes, offering a level of detail and accuracy far beyond conventional imaging techniques.



UAV flights were scheduled regularly throughout the growing season to document the progression of mildew infection from its early stages to full contamination across the vineyard. The imagery obtained was then processed to extract vital data, allowing us to calculate several key indices indicative of vine health and the presence of mildew. These indices are included but not limited to:

Normalized Difference Vegetation Index

(NDVI)=(NIR1-Red1)/(NIR1+Red1)

Modified Chlorophyll Absorption in Reflectance Index

(MCARI)=[(R701-R671)-0.2(R701-R549)]/(R701/R671)

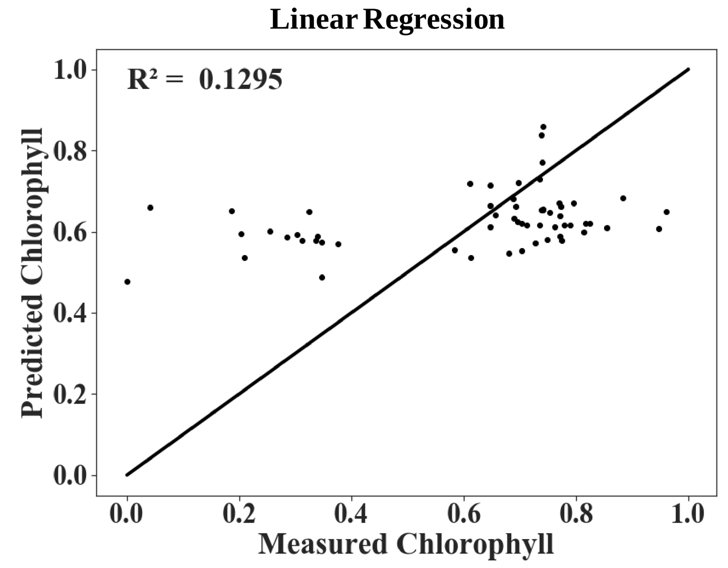
Normalized Difference Water Index

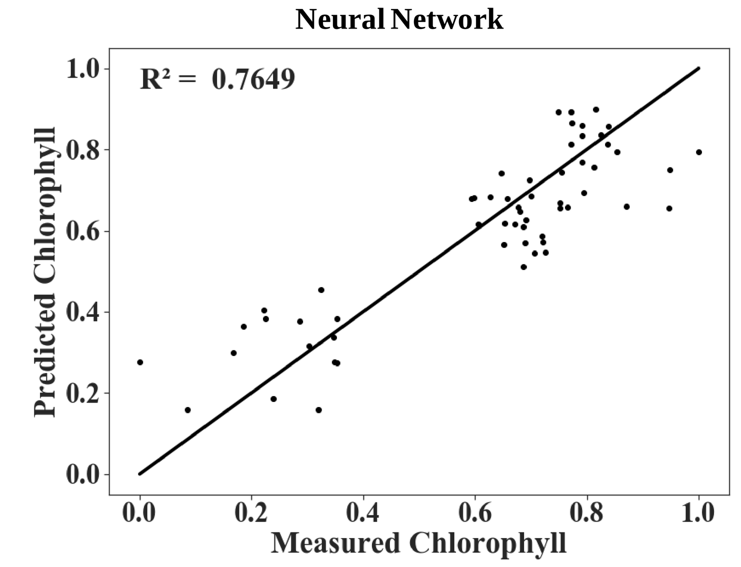
(NDWI)=(P864-P2200)/(P864+P2200)

Powdery Mildew Index

(PMI)=(R515-R698)/(R515+R698) – 0.5(R738)

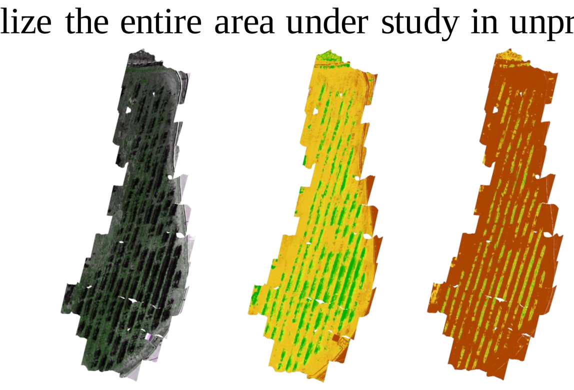
To validate the accuracy of these indices, we compared them against ground truth data collected via handheld sensors. Once the data and indices were confirmed for their accuracy in reflecting mildew presence, we proceeded to train machine learning models. These models are designed to expedite the calculation of the indices and enhance the prediction of mildew spread, aiming to streamline the process for more timely and effective vineyard management interventions. Leveraging insights from a former lab colleague's study on lettuce health prediction using linear regression and neural networks, our project aims to adopt a similar approach for vineyard mildew detection. The prior work, which accurately aligned spectral data predictions with chlorophyll ground truth, underscores the feasibility of our methodology. This precedent reinforces our confidence in using advanced machine learning techniques to analyze UAV-captured imagery for early and precise mildew identification in vineyards.





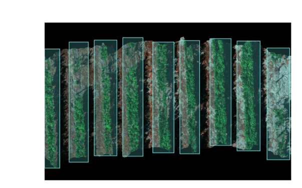
Results

Our project has made significant strides in the preprocessing phase, marking an essential foundation for our analysis of vineyard health and mildew detection. One of our successes was the stitching of hyperspectral data cubes to form a comprehensive image of the vineyard field. This process, though challenging and requiring adept handling of spectral software, was accomplished through practice, enabling us to visualize the entire area under study in unprecedented detail.



RGB NDVI MCARI

Furthermore, we have extracted pixel-level data from these comprehensive images. Utilizing LabelImg software, we manually labeled each vineyard area with bounding boxes, a step towards creating an accurate dataset for subsequent analysis and machine learning model training.



However, our progress encountered a significant challenge: the UAV-captured data predominantly represents stages where the vineyards were fully infected with mildew, lacking imagery from the early infection stages. This limitation has underscored the importance of capturing a more temporally diverse dataset to effectively train our models for early mildew detection.

Future Work

As we await the upcoming growing season to capture early-stage vineyard data, our focus shifts to leveraging our existing dataset. We will continue processing and calculating additional spectral indices related to overall vineyard health, beyond just mildew detection. This preparatory work is crucial for enriching our analysis and enhancing the predictive capabilities of our machine learning models once we obtain the missing early infection stage data.

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References

Bhandari, Subodh, et al. "Lettuce Plant Health Assessment using UAV-based hyperspectral sensor and proximal sensors." *Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping V*, 18 May 2020, https://doi.org/10.1117/12.2557686.

Khan, Imran Haider, et al. "Early detection of powdery mildew disease and accurate quantification of its severity using hyperspectral images in wheat." *Remote Sensing*, vol. 13, no. 18, 10 Sept. 2021, p. 3612, https://doi.org/10.3390/rs13183612.

Knaeps, Els & Sterckx, S. & Bollen, Mark & Trouw, Koen & Houthuys, Rik. (2006). Operational Remote sensing Mapping of Estuarine suspended Sediment concentrations (ORMES).

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