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Utilize VIS/NIR hyperspectral imaging to detect leafroll and red blotch-infected vines in your vineyard

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Grapevines face many threats, with viral diseases like grapevine leafroll and red blotch viruses being particularly challenging due to their elusive nature and lack of cures. Traditional containment methods involve identifying and replacing infected vines, a laborious and costly process. This highlights the need for innovative detection solutions. Advances in technology offer hope, promising more efficient methods. Since 2019, a research project at CSU Fresno has been investigating the use of hyperspectral imagery to improve the detection of leafroll and red blotch.

The Power of Hyperspectral Imagery

Vineyard management practices have been aided by a surge in digital tools capable of assisting with the optimization of production. Central to this trend is the development of sensors capable of delving deeper into the vine's spectral response to stress. These advanced technologies empower growers to monitor vine health with unprecedented precision, offering insights that were once inaccessible through conventional means. In 2019, a groundbreaking project was launched at California State University, Fresno, funded by the USDA, CDFA, CSU-ARI and F3, Fresno-Merced Future of Food innovative initiative, and in collaboration with experts from Cornell University (Dr. Marc Fuchs) and UC-ANR (Dr. Monica Cooper). The initiative aimed to revolutionize the detection of leafroll and red blotch viruses using hyperspectral imagery. But what exactly is hyperspectral imagery?

At its core, hyperspectral imaging is a cutting-edge technology that enables measuring an object's response to light absorption across a wide range of wavelengths (Figure 1). By analyzing the spectral signature of grapevines, researchers can glean valuable insights into their physiological and health state. For instance, variations in chlorophyll and anthocyanin concentrations manifest as distinct patterns in the visible spectrum (the portion of light wavelengths we interact with our eyes), while changes in cell structure influence near-infrared wavelengths (which are not visible to our eyes). Furthermore, water content and other chemical compounds (cellulose, sugar etc…) leave their imprint in the shortwave infrared domain. Crucially, grapevine diseases (such as Grapevine Leafroll and Grapevine Red Blotch) can alter these spectral signatures, offering non-invasive means of detection[1 2 3 4].

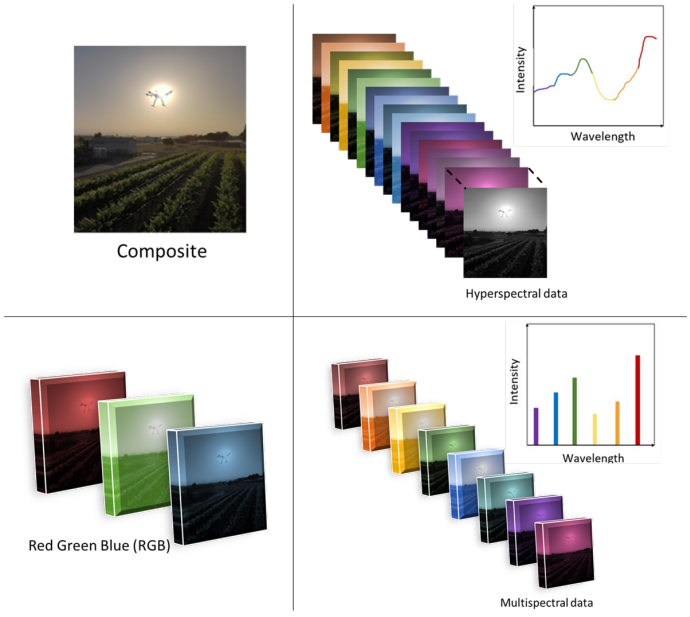

FIGURE 1. Difference between common RGB image and multi and hyperspectral data.

Promising Results from Laboratory to Field Conditions

Figure 2 illustrates the overall workflow of this study for detecting grapevine disease using hyperspectral imaging. Data acquisition involves collecting petiole samples and acquiring hyperspectral images in the laboratory or in the vineyard. These images are georeferenced to specific vine locations when needed. In the laboratory, PCR analysis is used to confirm infection status. Image preprocessing is performed for spatial alignment and image segmentation to extract only grapevine signal.

Finally, the model training and prediction integrates both field imagery and molecular data. Machine learning algorithms are used to analyze the processed images, enabling disease prediction at the vine level.

The project's first phase involved sampling 500 leaves from both healthy and virus-infected plants from a Cabernet Franc vineyard (by leafroll, red blotch, or both viruses). These leaves were then subjected to hyperspectral imaging within the controlled environment of a dark cabinet in the laboratory, capturing images across the 500 to 700 nm range. Machine-vision techniques, particularly Convolutional Neural Networks (CNN), were employed to analyze hyperspectral imagery and detect signs of infection in grapevines. CNNs are a type of deep learning algorithm that excels at image recognition tasks by automatically learning features from raw pixel data. During this phase, the CNN model achieved impressive results. For binary classification—distinguishing between infected vines (with red blotch or leafroll) and healthy ones—the model attained an accuracy of 87 % when symptoms were visible at post-veraison and 85.6 % when symptoms were not yet visible to the naked eye at pre-veraison (Table 1). This demonstrated the model's effectiveness in detecting infections even before visible symptoms manifested. Furthermore, in a more complex multiclass classification task aimed at identifying the specific virus infecting the vine, thus distinguishing between leafroll and red blotch, the CNN model achieved an overall accuracy of 76.9 %. This highlights the model's ability to differentiate between viruses based on subtle spectral variations[5].

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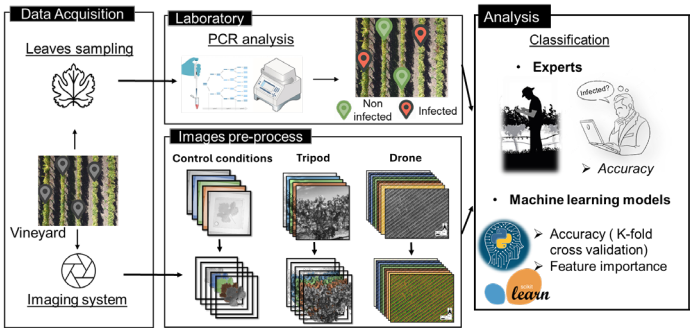

FIGURE 2. Workflow of the methodology used in this project.

Buoyed by these promising outcomes, the project advanced to its second phase, transitioning from the controlled environment of the lab to the dynamic conditions of the field. Utilizing the same hyperspectral camera, images of the side of 700 vines were captured in the same vineyard within the 500-850 nm range, focusing specifically on detecting the red blotch virus. When symptoms were not visibly apparent, a model achieved an overall accuracy of 68.6 % (Table 1). As the season progressed and symptoms became more pronounced, the accuracy improved significantly, reaching 76.6 % with a Support-Vector Machine (SVM) model (Table 1). This underscores the model's adaptability to real-world conditions and its efficacy in detecting infections even in the absence of visible symptoms[6].

In the third phase of the project, the approach was elevated by deploying a drone-mounted hyperspectral camera to capture images of ~300 vines during the post-veraison stage from 500 nm to 850 nm always in the same Cabernet Franc vineyard. This aerial perspective provided a comprehensive view of the vineyard, enabling it to assess vine health and identify infections across a potentially larger scale. Utilizing the spectral information, machine learning techniques were applied to classify vines as either infected or non-infected by red blotch. A support vector machine (SVM) model achieved an accuracy rate of 86.7 % (Table 1). Beyond overall model evaluation, classification accuracy was analyzed independently for symptomatic and asymptomatic cases. Symptomatic vines were identified as PCR-positive with visible signs of infection confirmed by expert assessment. In contrast, asymptomatic vines were also PCR-positive but lacked visible symptoms and were not flagged as infected by visual inspection. This targeted evaluation revealed that the model achieved up to 86.3 % accuracy in identifying asymptomatic infections. Those results further underscore the efficacy of hyperspectral imaging coupled with advanced data analysis in disease detection and management[7].

TABLE 1. Summary of the results obtained during the project.

Conditions	Material	Part of the vine	Season	Virus	Number of vines sampled	Expert accuracy	Model accuracy
Laboratory	Dark cabinet	Leaves	Post-veraison Pre-veraison	Leafroll & Red blotch	~500	50 % 50 %	87.0 % 85.6 %
Field	Tripod	Side canopy	Post-veraison Pre-veraison	Red blotch	~700	75.3 % < 50 %	76.6 % 68.6 %
	Drone	Top canopy	Post-veraison	Red blotch	~300*	83.6 %	86.7 %

* Preliminary data acquired in one field at one date.

Drone Model Validation

To assess how well the model generalize across locations and time, we tested it using data collected in September 2024 from three commercial Cabernet Sauvignon vineyards in Napa. The same drone and hyperspectral camera setup was used. Ground truth was established via PCR analysis on petiole samples collected during the flights (around 50 samples per vineyard). Model predictions were then compared to PCR results to evaluate accuracy. Accuracies on those new vineyards range from 75.2 % to 83.4 %. Prediction maps were produced for each vineyard (Figure 3).

Work in Progress

Building on these promising outcomes, the project continues to expand its dataset. Since 2023, additional grape varieties have been included incorporating also white varieties. Data collection using a NIR/SWIR-range camera began in 2023 and is ongoing through 2025, relying on both aerial and ground-based platforms. A major field campaign is planned for 2025, combining VIS/NIR and NIR/SWIR imaging from a plane to cover the Napa Valley floor, alongside PCR testing of 5,000 vines for validation.

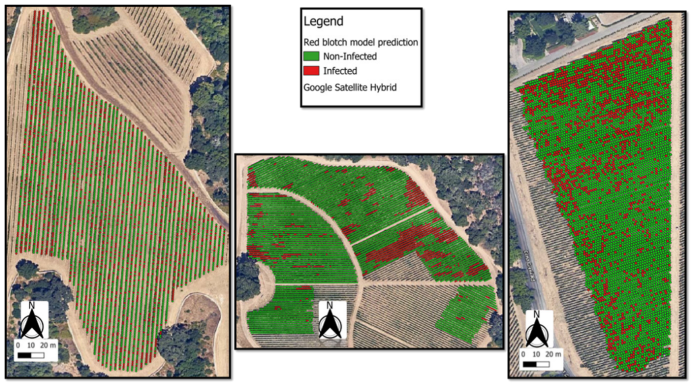

FIGURE 3. GRBV predictions map in 3 new vineyards in 2024.

Conclusion

This project represents a meaningful step toward improving vineyard monitoring by combining hyperspectral imaging with molecular diagnostics. The use of spectral data shows potential not only for detecting infections but also for capturing physiological indicators relevant to vineyard management. While initial results are promising, additional research is needed to confirm model accuracy under varying conditions and to evaluate operational integration at scale. As hyperspectral sensor costs continue to decline, the adoption of these tools for proactive disease monitoring becomes increasingly feasible, offering growers more timely and informed decision-making capabilities. The next step of the study involves scanning larger vineyard areas using airborne platforms, which could also help reduce the cost of a future commercial service. ■

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