Low-Cost Soil Sensing and Two-Level Classification for Early Stress Detection in Avocado Plants

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Motivation

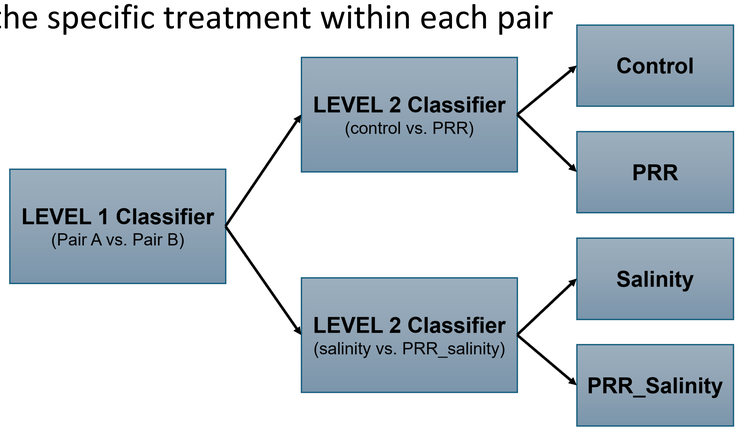
- Avocado is a high-value crop, yet vulnerable to salinity stress and Phytophthora root rot (PRR)
- Traditional health assessment of soil and leaf samples requires expensive benchtop equipment and expert knowledge.
- Low-cost soil sensors measure moisture and electrical conductivity periodically but there is a critical gap in understanding their real-world performance and limitations.
- We propose a novel approach that integrates soil sensor data with a two-level hierarchical classifier to enable early stress detection

Hardware & Dataset

- 72 greenhouse avocado trees (Thomas and PP40) split into four groups [Control, Salinity, PRR, Salinity + PRR]
- Each sensor costs around $25 combines a high-precision moisture strip with four stainless-steel EC electrodes
- Sensor's measurement are transmitted to a Raspberry Pi via Bluetooth 4.1 and run about three months on a CR2032 battery

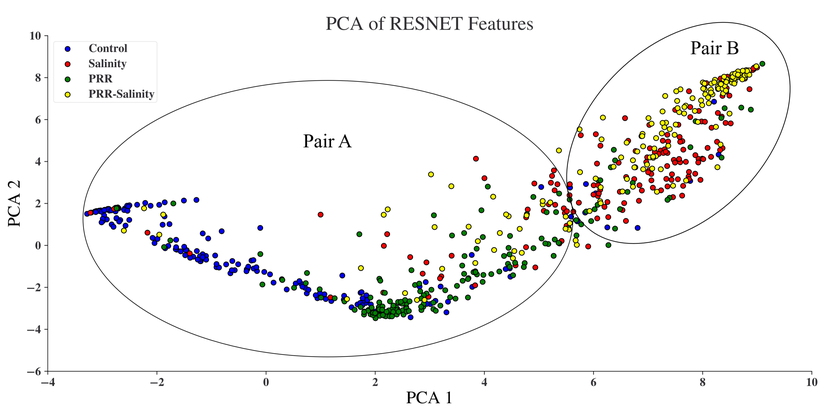
Our Method: Two-level Hierarchical Classifier

- Level 1 ResNet operates on the raw time-series data to separate: Pair A {control, PRR} and Pair B {salinity, salinity + PRR}
- Skewness and kurtosis are used as features capturing temporal trends and statistical variation.
- Level 2 Random Forest uses these features to classify the specific treatment within each pair

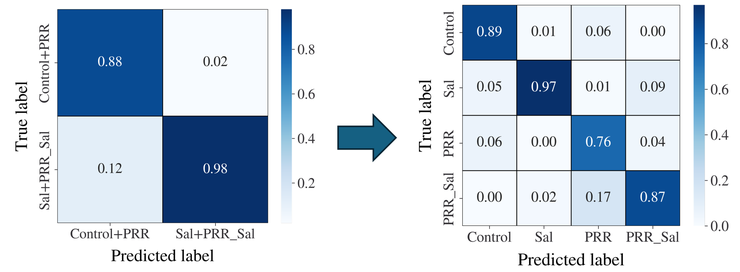


Why Two Levels?

- Certain groups overleap leading to poor detecting accuracy on baseline methods
- Pair A {control, PRR} and Pair B {salinity, salinity + PRR} are separated in feature space.



Evaluation Results



Level-1 accuracy = 92.4%

Level-2 accuracy = 86.5%

Table 1: Comparison of classification accuracy

Category	Method	Accuracy (%) Thomas	Accuracy (%) PP40
Traditional Machine Learning	Random Forest	58.6	44.5
	KNN	45.6	36.1
	SVM	44.1	39.5
Time-Series Classification	MUSE	60.1	42.5
Neural Networks	RNN (LSTM)	46.4	37.5
	ResNet	61.4	45.5
State-of-the-Art	HIVE-COTE 2.0	38.4	37.7
	HYDRA	43.9	39.1
	QUANT	59.4	43.6
Our Approach	Two-Level	**86.5**	**75.0**

25.1 - 29.5% improvement

Takeaways and Future Work

- Low-cost soil sensors paired with a two-level classifier detect salinity stress and PPR in avocado plants before visible symptoms appear.
- **Future work**
  - Comparing our approach against conventional lab-based analysis for detection accuracy and cost-effectiveness
  - Testing under outdoor conditions with fluctuating humidity and heterogeneous soil composition
  - Addressing generalizability beyond the experimental setup for broader applicability to precision agriculture.