

Abstract

As global population growth places unprecedented pressure on food and water supplies, modern farming must evolve into a more resource-efficient and sustainable industry. This dissertation, "Smart Systems for Precision Agriculture," addresses this urgent need by developing advanced data-driven frameworks that bridge the gap between high-level analytical modeling and practical field deployment. The research is organized around two complementary methodological tracks: spectral modeling to non-destructively assess crop status and temporal time-series forecasting to enable proactive irrigation management. In the first track, the research focuses on visible and near-infrared (Vis-NIR-SWIR) spectroscopy, a technique that enables rapid assessment of plant health without damaging samples. A recurring challenge in this field is the high dimensionality of spectral data, which often contains redundant information, complicating model deployment. Three case studies have been presented to overcome this barrier by introducing innovative wavelength-selection strategies that create compact, informative models suitable for low-cost, fixed-filter sensors. First, Case Study A introduces Calibrated CARS (CCARS), a method that reduced the number of spectral variables by 97% while maintaining high accuracy in lettuce health classification. By separating the data used for variable selection from that used for model development, this approach significantly mitigates the risk of overfitting. This drive for efficiency is further advanced in Case Study B, which proposes a novel hybrid selector, iGA-BOSS, compared with state-of-the-art wavelength selection algorithms. This method combines the global search capabilities of Genetic Algorithms (GA) with the sparsity-promoting nature of Bootstrapping Soft Shrinkage (BOSS), achieving 0.95 accuracy with only 20 wavelengths while simultaneously reducing computational runtime by 40%, surpassing the performance of other methods. The practical hardware implications of this work are most evident in Case Study C, which focuses on detecting internal browning in cucumbers caused by the fungal pathogen *Mycosphaerella melonis*. The first part of this work demon-

strated that the fruit's tip provides twice the class separability as other locations. Then, the best wavelength was selected using the fCOVSEL algorithm on a 2014 dataset. These selected variables have been used to train on a new 2025 dataset, achieving 97.44% accuracy with just 8 wavelengths, providing a direct blueprint for high-throughput, low-cost sorting systems. The second methodological track focuses on forecasting soil moisture. Case Study D evaluates various recurrent neural network architectures —RNNs, GRUs, LSTMs, and BiLSTMs—to predict soil matric potential, a key indicator of irrigation needs. These models demonstrated exceptional short-term predictive performance, achieving R^2 values of approximately 0.99. A critical finding was that deeper sensing depths (-40 cm) provide significantly more stable accuracy over extended periods, offering a reliable basis for reducing over-irrigation in professional orchards. In this work, rather than merely seeking theoretical accuracy, the thesis prioritizes algorithmic sparsity and hardware feasibility, proving that critical agricultural states can be detected with a handful of wavelengths. Furthermore, by consistently employing permutation testing and learning-curve diagnostics, the research moves beyond standard validation to ensure that these "smart" systems are genuinely robust and ready for real-world application, especially for agriculture. In conclusion, these works provide a foundation for future unified decision-support systems that integrate immediate spectral diagnostics, with embedded spectral devices and long-term predictive forecasting to optimize the agricultural loop from observation to intervention.