Executive Summary

Doctorate in Computer Science (DCC) — Tecnológico de Monterrey

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I. Overview

This summary presents the doctoral proposal titled *"Smart Viticulture: Integrating Fiber-Optic Interferometric Sensing and Machine Learning for Vineyard Optimization."* The project seeks to develop a hybrid optical–intelligent sensing system for vineyard monitoring, integrating multimode fiber interferometry, computer vision, and AI-based modeling to enable precision agriculture.

II. Motivation and Research Gap

Viticulture quality depends on controlling parameters such as pH, humidity, and grape maturity. Current sensing methods are either invasive or lack automation. Fiber-optic sensors offer high sensitivity and resistance to interference, yet few works combine them with artificial intelligence and visual data fusion. This research addresses the gap by proposing a system capable of correlating optical spectra, agronomic images, and machine learning models.

III. Objectives

- Design and simulate an optical interferometric sensor based on multimode fiber (MMF).
- Generate synthetic spectra and validate theoretical models through numerical simulation.
- Train AI models (Random Forest, SVR, MLP) to predict pH from spectral features.
- Integrate computer vision for multimodal fusion (optical + visual data).
- Develop and validate a physical prototype under laboratory conditions.

IV. Methodology

The methodology combines theoretical derivation, numerical modeling, and machine learning analysis:

1) **Optical Model:** Interferometric relation $\lambda_m = 2n_{\mathrm{eff}}L/m$ with sensitivity $\Delta\lambda/\Delta pH = 2L\alpha/m$.
2) **Simulation:** 1000 spectra with Gaussian noise ($\sigma = 0.02\,\mathrm{nm}$), processed via Savitzky–Golay filtering.
3) **AI Training:** Comparative study of regression models; MLP achieved RMSE $\approx 0.12\,\mathrm{pH}$ and $R^2 = 0.91$.
4) **Validation:** Sensitivity $0.089\,\mathrm{nm/pH}$ within literature values.

V. 12-Month Development Plan

Jan–Feb: Theoretical framework and bibliographic review.
Mar–Apr: Full simulation and dataset generation.
May–Jun: Machine learning model optimization.
Jul–Aug: Integration of computer vision (CNN-based).
Sep–Oct: Prototype fabrication and calibration.
Nov–Dec: Manuscript preparation and open data release.

VI. Expected Contributions

- A validated hybrid optical–AI model for vineyard monitoring.
- Publication-ready dataset and reproducible simulation code (FAIR-compliant).
- Potential article submission to *IEEE Photonics Journal* or *Sensors (MDPI)*.
- Foundation for applied collaborations within the DCC (computer vision, intelligent sensing).

VII. Conclusion

The project provides a rigorous and achievable roadmap for developing an intelligent optical sensor for sustainable viticulture. It demonstrates doctoral-level readiness in simulation, data science, and interdisciplinary research aligned with DCC priorities.

Keywords

Optical fiber sensing, multimode interferometry, machine learning, computer vision, precision agriculture.