

Bio-Impedance Measurements for Plants Health Evaluation

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Abstract

In recent years, smart agriculture has experienced significant growth, driven by the need to optimize resource use and improve crop resilience amidst climate change. This dissertation evaluates the diagnostic potential and practical limitations of a low cost, in vivo sensing approach based on plant stem electrical behavior, specifically a simplified parameter referred to as *stem frequency*, which is strongly correlated with stem electrical impedance. While previous studies demonstrated the potential of bio-electrical sensing, they were largely restricted to short term laboratory setups or high cost, complex impedance analyzer. A key gap in prior research was the lack of long term, multi environment validation and accounting of high biological heterogeneity.

This thesis addresses these gaps through a multi stage validation campaign spanning controlled, semi controlled, and real world agricultural scenarios. Initial climate chamber trials established that under optimal hydration, stem frequency tightly tracks ambient microclimatic drivers such as Vapor Pressure Deficit (VPD); however, this environmental coupling breaks down under water deficit, where signal dynamics align with soil water potential. Subsequently, a greenhouse campaign involving 73 tomato plants evaluated the system under both abiotic (drought) and biotic (*Fusarium oxysporum*) stress conditions. Utilizing linear mixed effects modeling adjusted for short term temporal autocorrelation (via a second-order autoregressive $AR(2)$ structure on a 20-minute sampling interval combined with daily cycles), the study demonstrated a statistically significant population level decline in stem frequency under water deficit ($p < 0.05$). Conversely, biotic stress induced by *Fusarium* showed no statistically separable signal once serial correlation was properly controlled. Unsupervised Dynamic Time Warping (DTW) time series clustering further highlighted high inter plant variability, revealing that raw signals cannot currently serve as standalone diagnostic classifiers for individual plants.

Finally, a multi season field deployment in a commercial apple orchard demonstrated the operational durability, electrical stability, and seasonal consistency of the embedded sensors over more than a full year, confirming that stem frequency follows plant dynamics across phenological transitions.

Overall, this work demonstrates that while stem frequency is not yet ready for uncalibrated, stress type-specific disease diagnosis, it represents a promising, highly scalable, and cost effective tool for tracking plant water status. These findings establish a realistic baseline for the technology, highlighting the need for future hardware refinements and multivariate modeling to advance real time plant health monitoring.