When Plants Speak: Real-Time Electrophysiology-Driven Early Plant Stress Detection Through a Multi-Stage Embedded Biopotential Acquisition Pipeline and Edge-Deployed Supervised Machine Learning

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Despite modern agriculture boasting a profound amount of environmental data, there is a lack of tools that provide direct insights into a plant's physiological state. Traditional plant monitoring systems look to analyze environmental abnormalities based upon soil moisture levels, temperature, or other external measurements that provide indirect stress approximation, often after irreversible damage has already occurred. Due to plant stress responses propagating internally before resulting in visual cues, methods for sensing stress at its physiological onset are crucial for effective intervention. This embedded system framework sought to utilize plant electrophysiological signals (electrical activity generated by internal plant signaling processes) in order to predict stress utilizing trained edge-deployed artificial intelligence. An embedded system was developed to collect microvolt-level electrophysiological signals from plant tissue through means of non-invasive electrodes, a high-input-impedance instrumentation amplifier, analog filtering, and an ADC integrated with a low-power microcontroller. Signals were then sampled at low frequency, digitally filtered, and processed in real time. Data was collected from plant species after simulating drought conditions and fed through a lightweight supervised logistic regression model on the microcontroller, which differentiated between binary stress states. The electrophysiological activity observed across repeated trials featured consistent, stress-dependent changes facilitating detection with edge AI. Importantly, electrophysiology-based detection resulted in significant lead times when compared to the initial onset of visual stress indicators.

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