ADVANCED SENSORS AND AI-DRIVEN DATA ANALYSIS FOR CONTINUOUS MONITORING AND OPTIMISATION OF PHOTOBIOREACTORS

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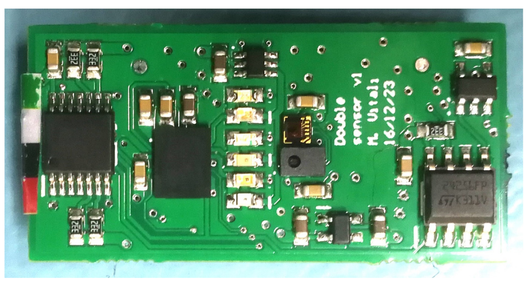
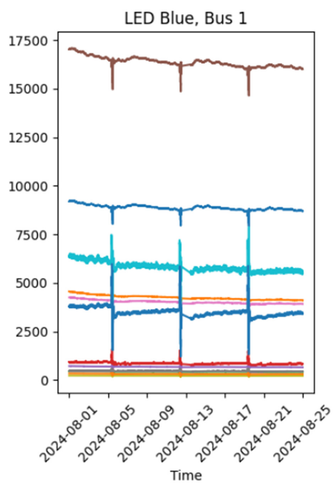
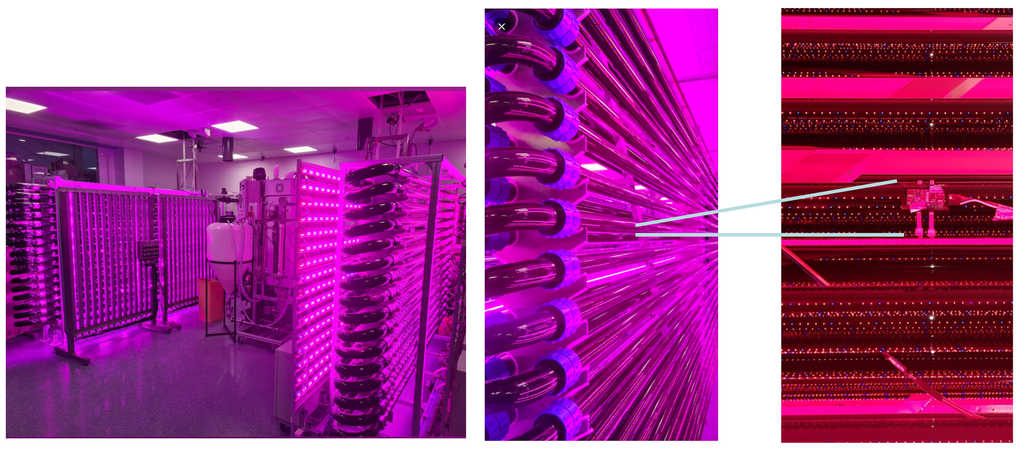
- **Innovative PBR Automation:** fully automated photobioreactor operation and adaptive process control based on optical signals measured from outside.
- **Advanced Sensor Monitoring:** Wireless multi-sensor arrays continuously record spectral absorption and scattering, fluorescence, temperature, CO_2, and pH.
- **Data Fusion and State Estimation:** Multi-sensor signals are merged with physical growth models to derive robust, real-time estimates of biomass concentration, metabolic activity, and chromophore concentration (Chl *a*, carotenoids).
- **AI-Driven Optimization:** Cloud-based machine learning algorithms analyze state data to identify optimal illumination spectra, gas flow rates, and nutrient regimes for enhanced growth efficiency.
- **Autonomous Feedback Control:** Closed-loop regulation dynamically adjusts CO_2 supply, temperature, nutrient (N/P) dosing, and harvesting frequency to maximize biomass yield and omega-3 fatty acid content.

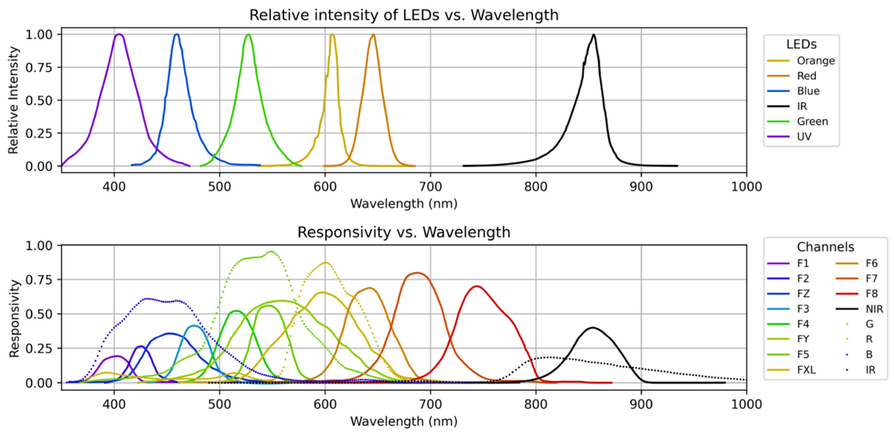


Spectral data is recorded by our proprietary chip, which features six LEDs providing broad-spectrum illumination (IR to UV). The data is captured using 14 discrete spectral channels and cross-referenced with parallel measurements from a specialized RGB chip designed for its wide dynamic range.

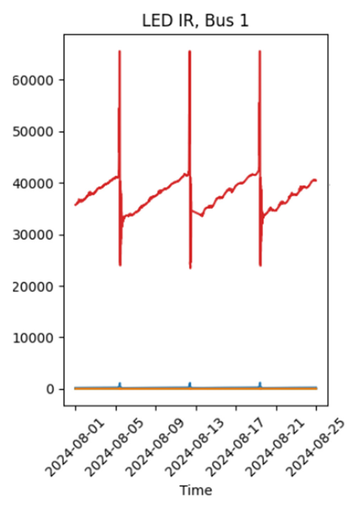
Raw data consists of wavelength-specific signals (upper graph) representing either LED backscatter or fluorescence. The Infrared (IR) backscatter exhibits a strong, direct correlation with the momentary growth rate (lower graph). This correlation enables the continuous calculation of the algae's current growth rate using only the measured IR absorption (right side).

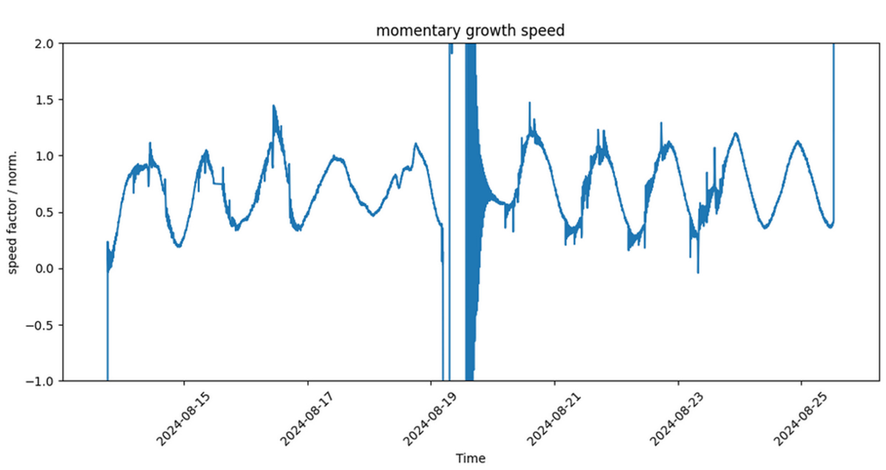




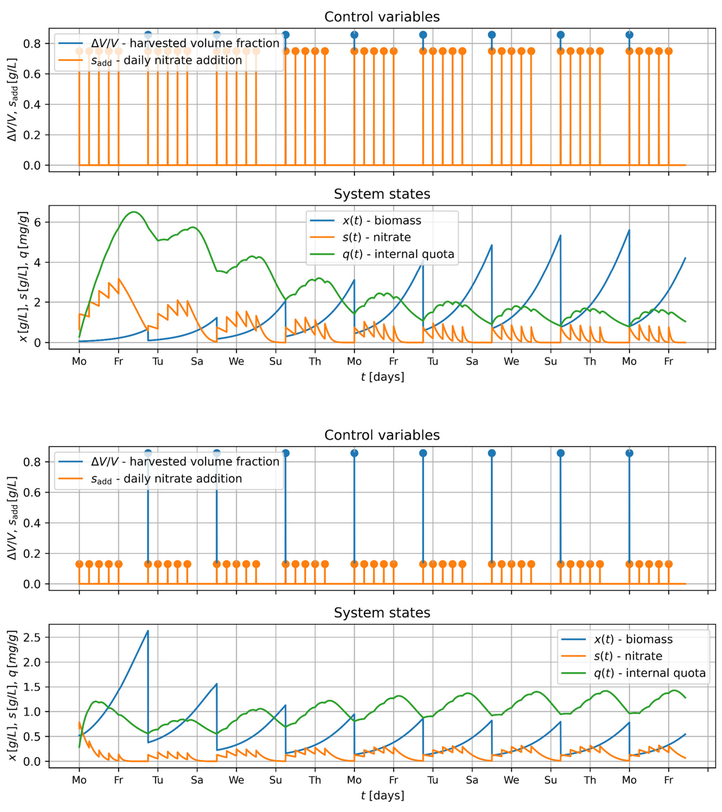


Spectral LED intensities (top) and spectral detector channel responsivities (bottom). Data is digitized from the datasheets with automeris.io

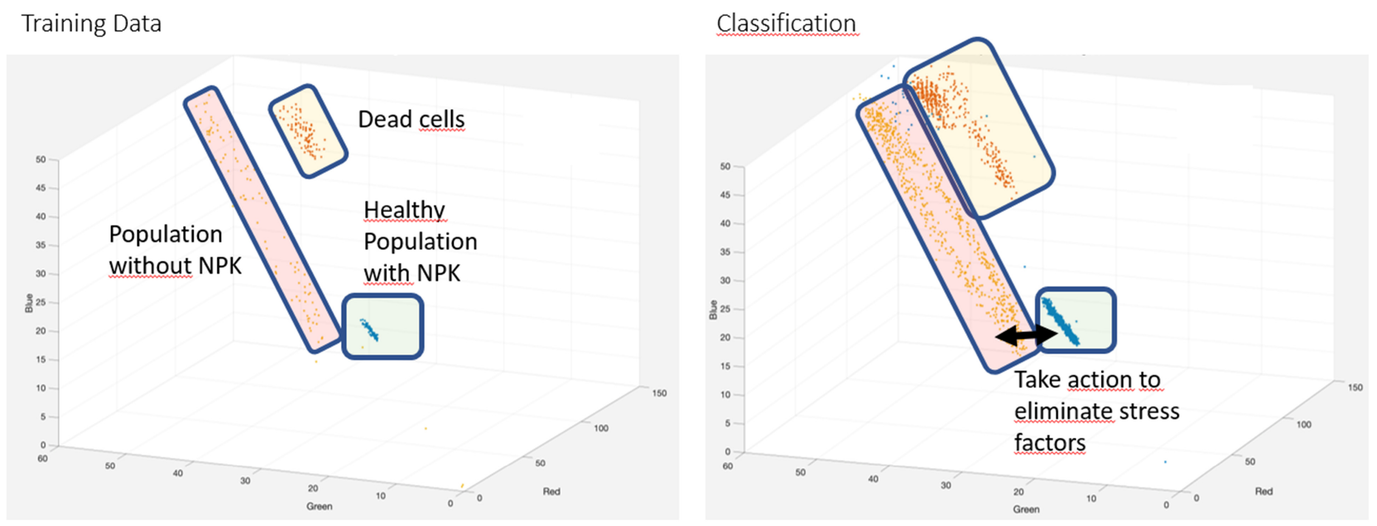




The momentary growth speed is calculated from the sensor data with a resolution of 10 min.



A mathematical model enables the calculation of biomass growth x(t) and nitrate concentration s(t) in solution as a function of key control parameters, such as the added nitrate s_{add} and the harvested volume fraction ΔV/V. The plots (left) contrast two different scenarios: A nitrate-saturated algae culture, which exhibits significantly faster biomass growth (upper panel), and a nitrate-limited culture, which shows relatively lower biomass production (lower panel). The primary goal of this project is to determine the optimal setpoints for the control parameters, including: spectral light composition and light intensity over time, added nitrate and phosphate concentrations, CO_2 supply, and the harvesting rate and fraction. Furthermore, the model can predict deviations from the regular growth curves, allowing for the early indication of disruptive events such as cell aggregation, microbial contamination, or other environmental stresses within the Photobioreactor



AI enables the classification of algae and allows rapid identification of nitrate deficiency. This allows appropriate measures to be taken (in this case, the addition of nitrate).

The aim is to establish a multidimensional correlation of sensor data to determine biomass growth, metabolic state of the cells, chlorophyll and omega-3 fatty acids and optimize CO_2, temperature, light and nutrients for a fully automised photobioreactor.

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