Synthetic Photoswitchable Expression and Temporal Response Analyzer (SPECTRA): An Integrated 3D-Printed Hardware Platform for Real-Time Optogenetic Control and Growth Modeling

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Optogenetics leverages genetically encoded, light-sensitive proteins to achieve high spatiotemporal resolution in cellular regulation. However, current chimeric proteins suffer from slow switch off kinetics because they remain active after the light stimulus stops. This results in signal smearing and synaptic fatigue, hindering the development of high-fidelity optogenetic prosthetics. Current testing platforms are typically designed for static induction, making it difficult to study and screen for fast switch off variants. This project presents SPECTRA (Synthetic Photoswitchable Expression Control and Temporal Response Analyzer), a 3D-printed, ESP32-coordinated platform designed to bridge this gap. SPECTRA provides a light-shielded environment for a specialized strain of Saccharomyces cerevisiae engineered with photoswitchable pMag and nMag proteins, which are fused with Gal4 domains to function as light-activated transcription factors that, upon light exposure, dimerize to activate the URA3 gene for cell growth. By 3D printing the chamber, SPECTRA creates the noise-free environment to minimize optical crosstalk. Within this chamber, an ESP32 controlled LED light is used to generate programmed blue-light pulses while the built-in camera takes time-lapse imaging to track colony expansion. By pulsing the light at specific frequencies, SPECTRA imposes a kinetic selection pressure, forcing yeast to "cycle" their protein state to survive and effectively filtering for the fast-switching variants required for neural applications. SPECTRA demonstrates that sophisticated optogenetic optimization can be achieved in a portable, low-cost format, offering a critical blueprint for the next generation of responsive, high-fidelity neuro-regenerative tools.

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