Developing a low-cost, real-time, and high resolution taxonomic and phenotypic characterization platform for microalgal cultivation systems

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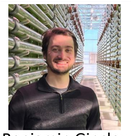
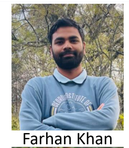

Benjamin Gincley


Farhan Khan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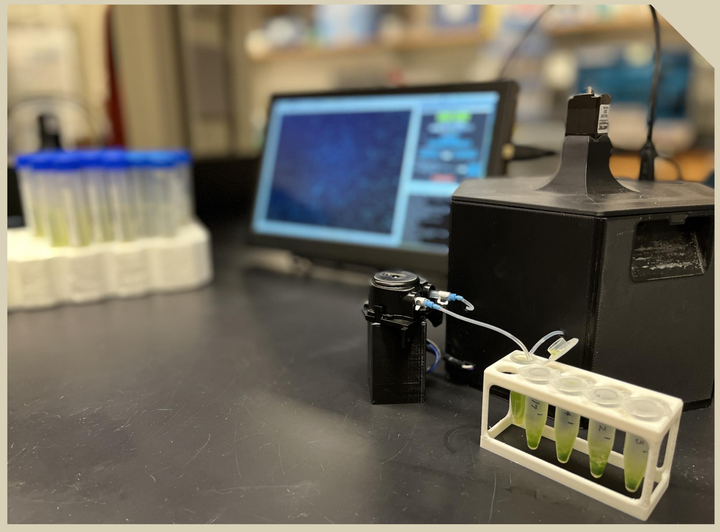
PhycoSight

Abstract

Improving the commercial viability of microalgae-based bioprocesses will require the optimization of their cultivation for lipid yield. To advance process control and optimization of microalgal cultivation, we have previously developed ARTiMiS: the Autonomous, Real-Time Microbial 'Scope. Using flow cytometry as a ground truth for lipid content, we present a novel application of the deep learning architecture, variational autoencoders (VAEs), to encode single cell lipid content as a continuous state variable measurable directly from low-cost light microscopy images of unstained samples captured on the ARTiMiS.



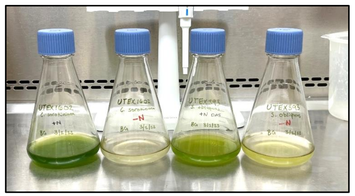
Motivation

Microalgae are a promising collection of organisms for the future of agronomy due to their ability to be grown in non-arable locations to produce valuable lipid-based bioproducts – from biofuels or plant-based nutraceuticals to dietary supplements. Yet, traditional methods of characterizing lipid content in algal biomass require tedious sample processing and the samples must often be analyzed on expensive laboratory instrumentation.

Research Questions

1. Can low-cost microscopic techniques capture lipid accumulation phenotype within algal cells?
2. Can a lipid accumulation phenotype be identified at a single cell level using advance deep learning methods?
3. Is the shift in average lipid accumulation phenotype over time driven by lipid content, or a different measurable parameter?
4. In semantic terms, what information is the variational autoencoder encoding?

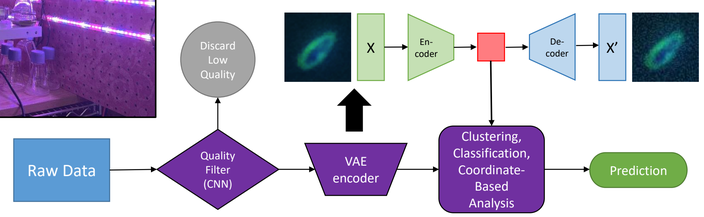
Methodology



Chlorella and *Scenedesmus* were cultivated in two conditions: media replete with nitrogen (N-replete) and media without nitrogen (N-deplete).

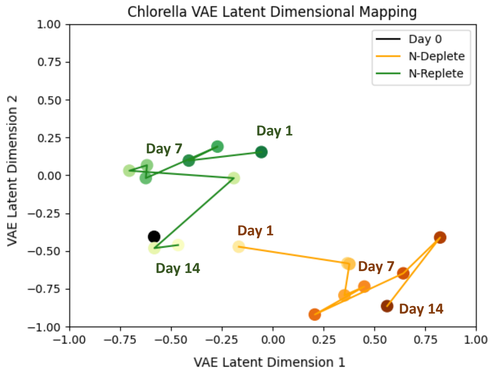
Lipid content was measured via flow cytometry with the dye BODIPY$^{505/515}$.

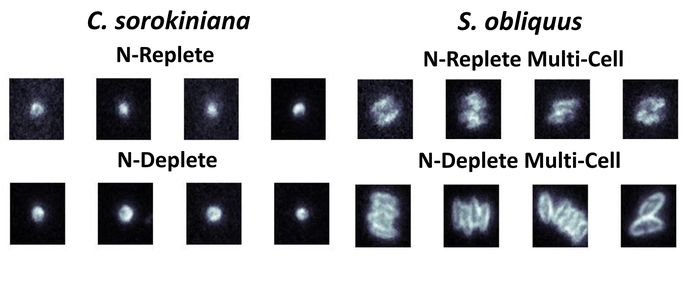
Microscopy data was pre-processed with an image quality filter prior to encoding by a variational autoencoder (VAE).



Key Results

- Intracellular lipid content increased in the N-depleted condition incubation time.
- The latent space coordinates encoded by a VAE model trained on ARTiMiS data demonstrated a strong correlation with the lipid signal.
- The VAE encoding displayed clustering by media condition, with a directionality coinciding with lipid signal.
- Latent dimensions correlate with visual traits including cell "fuzziness" and size.





Key Takeaways

1. Light microscopy data can be used to measure microalgal lipid content using the ARTiMiS imaging platform without the need for sample staining.
2. Variational Autoencoder deep learning model can encode image data into a coordinate space with strong correlation with lipid level.
3. Lipid-accumulating cells can be generally described as larger and less "fuzzy" than cells grown in the replete nitrogen condition.
4. This approach may be extendable to other continuous phenotypes, such as stress responses to pests, predators, or pathogens.
5. Low-cost hardware (ARTiMiS) and software (PhycoSight) can significantly enhance access to algal cultivation and advance its reliability.