Cyber-Physical Sensing, Modeling, and Control for Large-Scale Wastewater Reuse and Algal Biofuel Production

Project Goals

- This project aims to develop an integrated set of cyber-physical sensing, modeling, and control methods and tools to support large-scale intelligent Wastewater Reuse and Algal Biomass (iWRAB) production.
- Our **project goal** is to increase the algal productivity from <20 g/m^2/day in current practice to >60 g/m^2/day using the proposed algal membrane bioreactor (A-MBR) and cyber-physical system (CPS) technologies, demonstrating a feasible pathway towards green energy production and water reuse.

Background

- **Wastewater Treatment**: Many wastewater treatment plants are discharging treated wastewater containing significant amounts of nutrients, directly into the water system, posing significant threats to the environment.
- **Biofuel Green Energy**: Bon-fossil green energy is very important for environment, energy security, and sustainable economic development.
- **Large-scale algal cultivation and production** has been recognized as one of the most promising and attractive solutions for simultaneous wastewater treatment and biofuel production.

Algae biofuel has the following advantages: (a) **Impressive productivity Non-competitive with agriculture; (b) simultaneous treatment of wastewater; (c) mitigation of CO_2.**



Research Team

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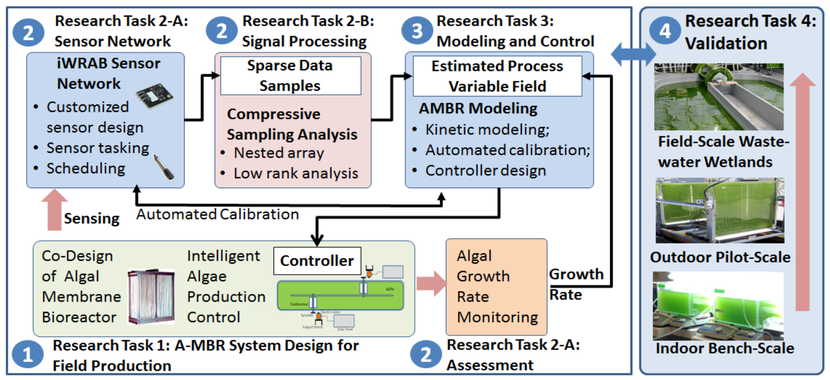
- **University of California, San Diego:** Piya PAL: ECE

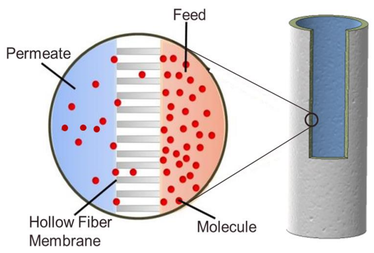
Research Overview



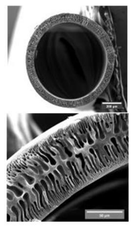
Project Results

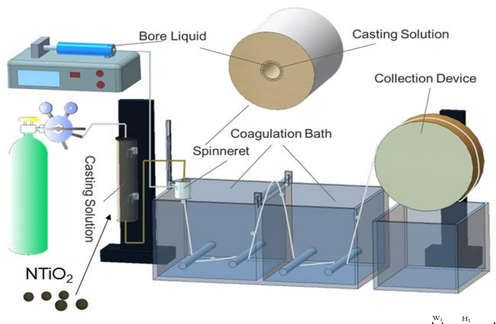
Research Task 1: *Fabrication and modification of the hollow fiber membrane (HFM)*

Membrane can be generally defined as a selective barrier between two phases and selectivity is inherently important to a membrane or a membrane process



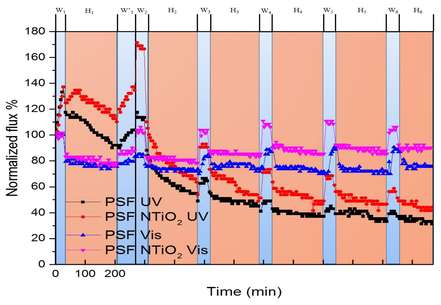
Schematic representation of a two-phase system separated by an HFM


Cross section of a hollow fiber



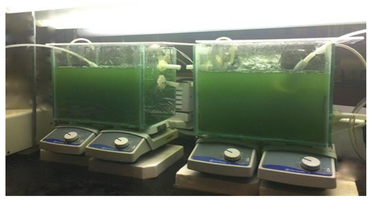
Fabrication process
A hollow fiber was formed when the casting solution was pumped at a constant pressure by nitrogen cylinder and a bore fluid of DI water was extruded by syringe pump simultaneously through a spinneret.

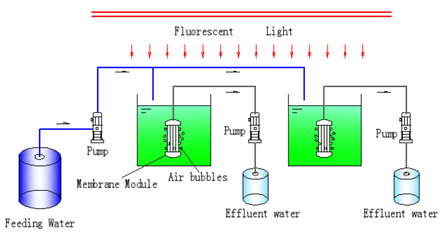
The PSF membrane modified with $NTiO_2$ showed the best antifouling property by visible light irradiation



Research Task 2: *New Design Of Algal Membrane Bioreactor For High-density Field Cultivation.*

Algae Membrane bioreactor System



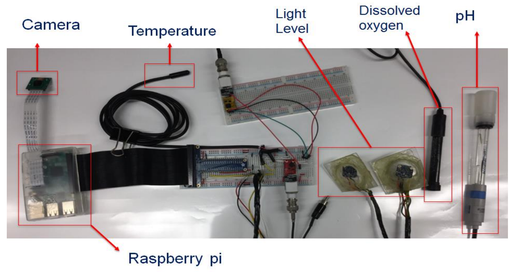


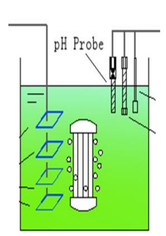
- Total volume (L): 9.0 each
- Dimension (cm):25 ×18 ×21 (L×W×H)
- SRT (d) : 10
- HRT (d) : 1

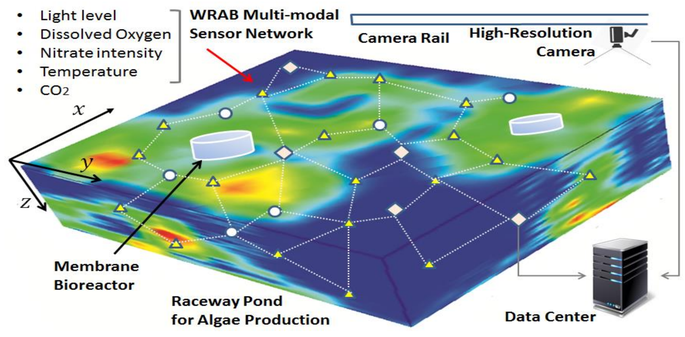

Algae membrane bioreactor tanks (Bench-Scale)

Research Task 3: *iWRAB sensor network design and Signal Processing*

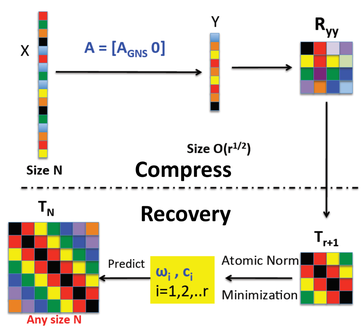
Design a network of multi-modal sensors for real-time in-situ monitoring of key environmental variables and assessment of the health conditions of algal cultures.







Compressive Sampling
Investigate compressive sampling and nested array methods for accurate reconstruction of the variable field with fine resolutions in space and time from a minimum number of active sensors. We consider the problem of compressively sampling wide sense stationary random vectors with a low rank Toeplitz correlation matrix.



Denoise, Parameterize, and Predict

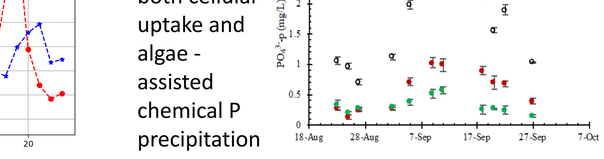
$$\mathbf{t}^{\#}_{(n)} \triangleq \arg\min_{\mathbf{u}\in\mathbb{R}^n} \|\tilde{\mathbf{t}}_{(n)} - \mathbf{u}\|_2 \quad s.t.\ \mathcal{T}(\mathbf{u}) \succeq 0$$

$$\mathcal{T}(\mathbf{t}^{\#}_{(n)}) = \mathbf{V}^{\#}_{n\times n'}\mathbf{D}^{\#}(\mathbf{V}^{\#}_{n\times n'})^H + \sigma^{\#}\mathbf{I}_n$$

$$t^{\#}_m = \sum_{i=1}^{n'} d_i^{\#} e^{j2\pi f_i^{\#} m}, \quad n \leqslant m \leqslant N-1$$

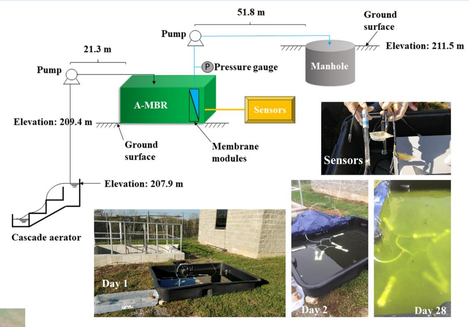
Research Task 4: *Data-driven knowledge-assisted modeling and control of iWRAB.*

- Construct data-driven knowledge-based kinetic models for high-density algae cultivation using the A-MBR technology.
- Develop layered and compartment models for algal cultivation in the field.

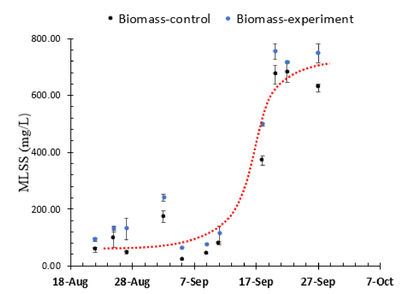


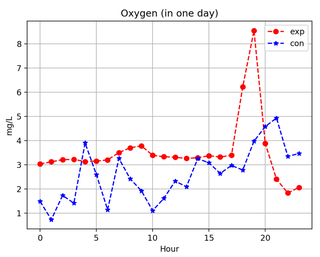
Research Task 5: *Field Evaluation at the Columbia Waste Water Treatment Plant.*

From May 2018 – Oct 2018, we conducted field test of our CPS system in the Boone County Waste Water Treatment Plant, demonstrating that the CPS technology is able to improve the algae biomass production in an outdoor environment by 50%.




Dissolved Oxygen (sensor data)





P removal is based on both cellular uptake and algae - assisted chemical P precipitation