Design & Development of a Novel Spectrophotometry Based Sensor for Cyanobacterial Growth Monitoring

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Industry standard benchtop spectrophotometry is time-consuming, expensive, has low data throughput, and is prone to user error [1]. Spectrophotometric sensors measure light attenuation/absorbance, which correlates to the bacterial concentration [2]. The biggest drawback, however, is that non-linear attenuation and multiple scattering events limit these sensors to a fixed range of concentrations [3]. This project looked at developing an improved spectrophotometry sensor for photobioreactor integration, enhancing experimental power and increasing research accessibility.

Initial Design

The initial design was a variable-pathlength fiber optic sensor. This approach reduces multiple scatter events without dilution, as absorbance and optical pathlength are proportional [4].

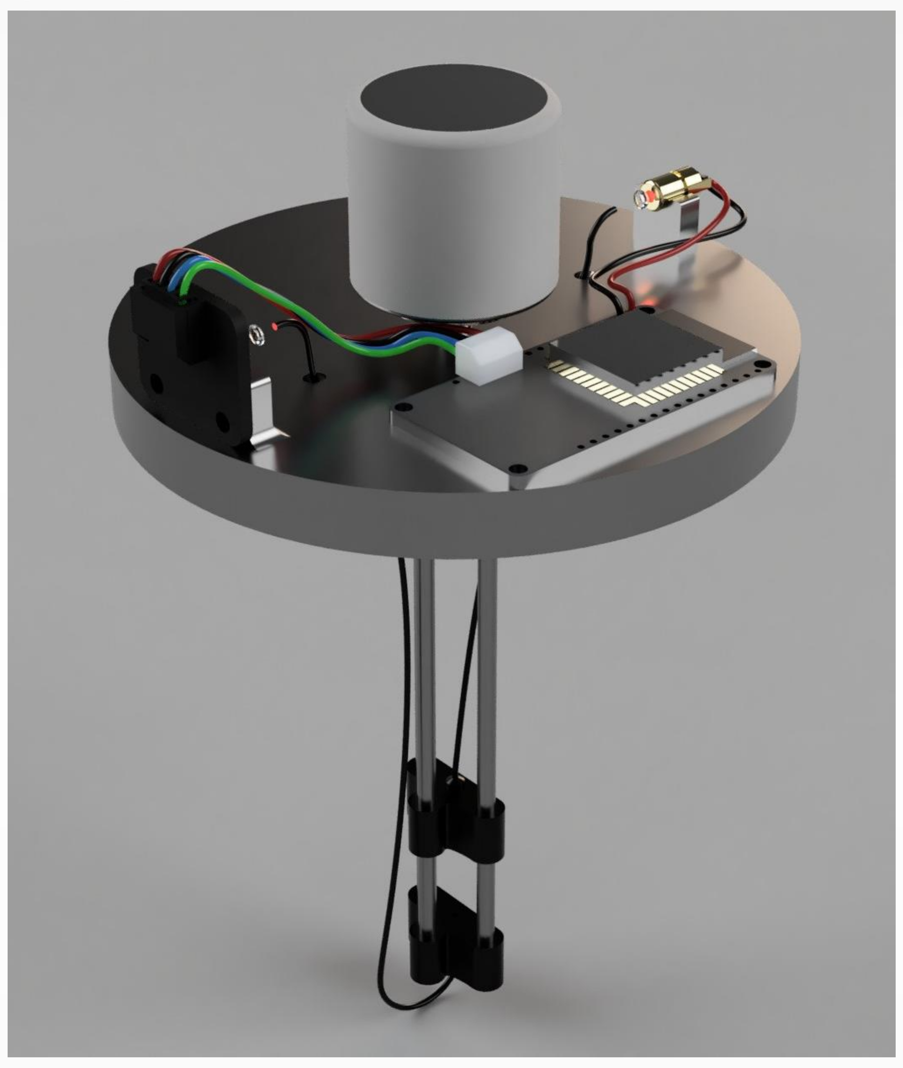

Figure 1: CAD render of initial design.

Pathlength adjusted using:

- Piston-displacement equation and Hill Climb optimisation autocalibration [5]. Error is shown in **figure 2.**
- Motor controlled by an ESP32 microcontroller.
- A luminosity sensor recorded transmitted light [6].

PMMA optical fibers were used as LASER waveguides for their IR transmittance, and cost. Allows for in-situ sensing, ambient filtering (**figure 3**) and improving signal/noise ratio.

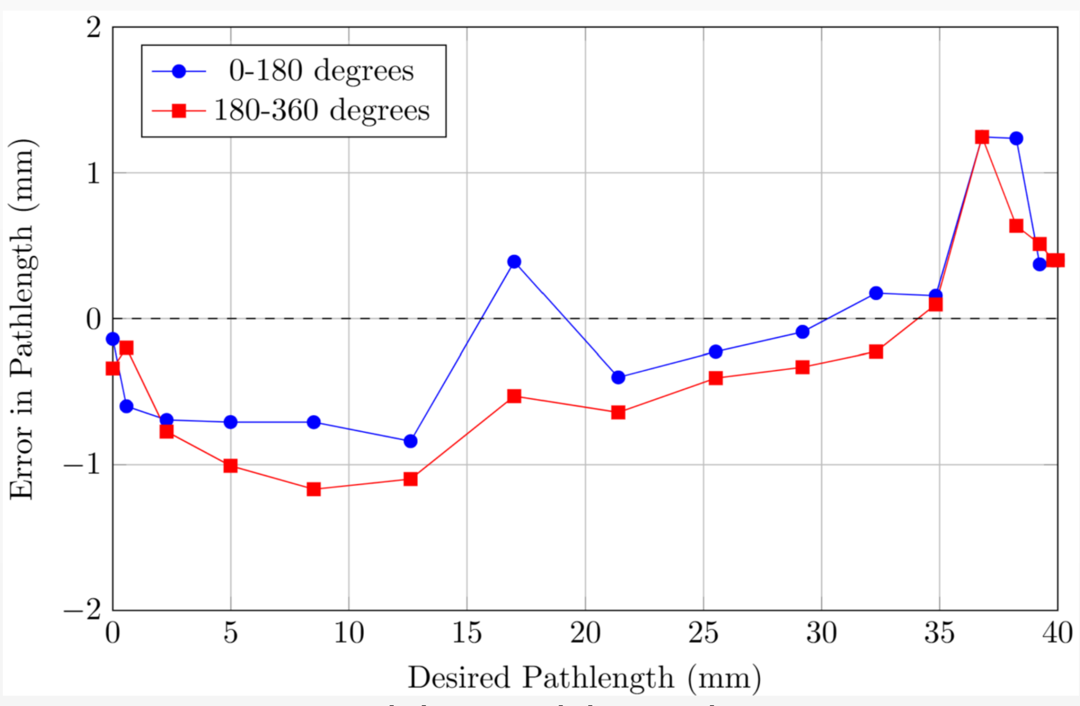

Figure 2: Variable pathlength error analysis for full motor rotation.

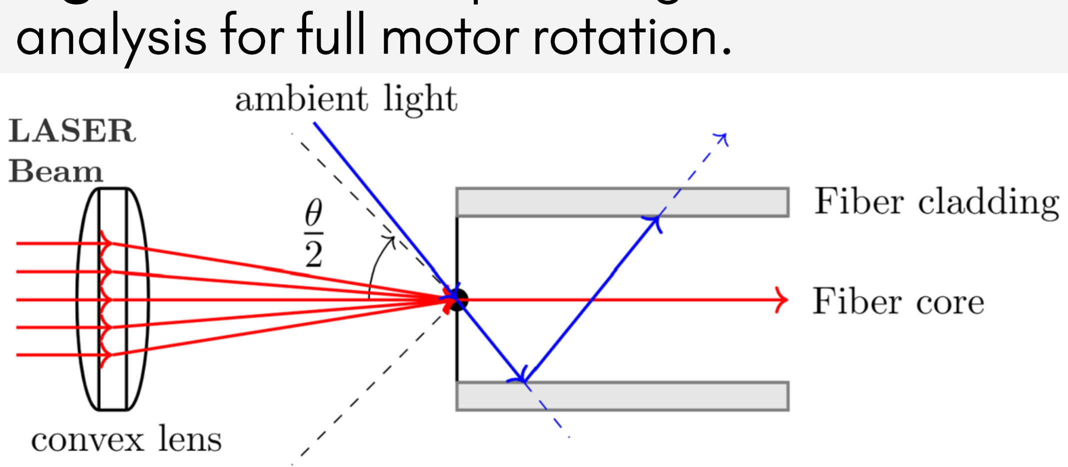

Figure 3: LASER-to-fiber optic coupling.

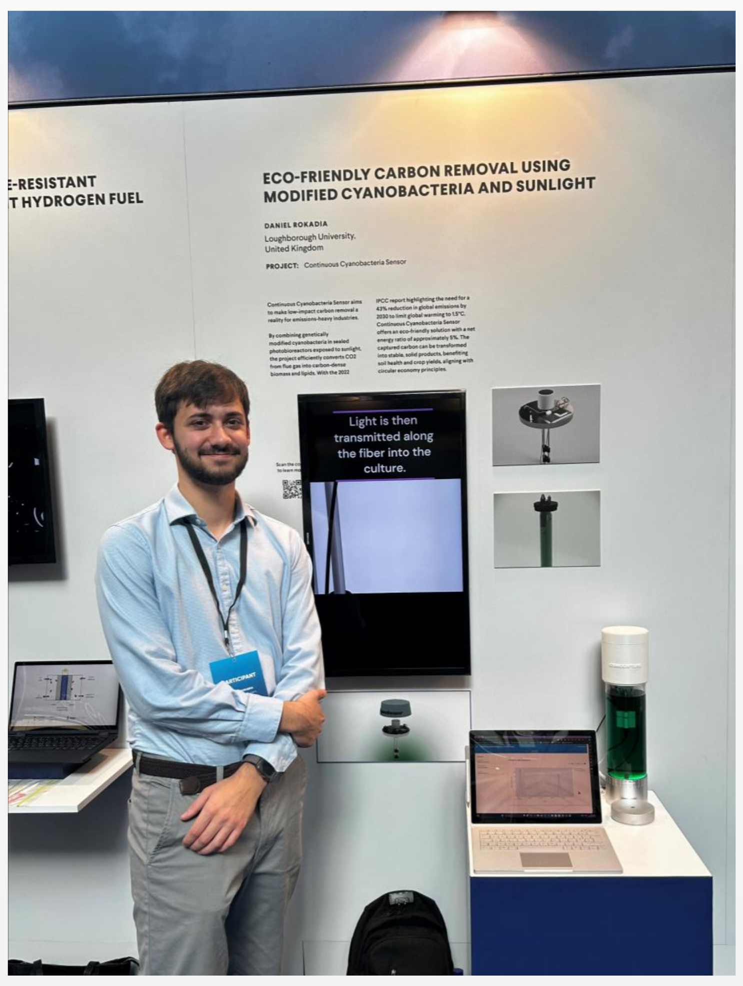

Figure 4: Showcase at Prototypes For Humanity Expo and competition, Dubai 2023.

Improved Design

The second design has; a 780nm LASER, reducing pigment overlap and improving sensitivity; a collimated fixed pathlength; a novel cyclic LASER intensity measurements (CLIM); custom sensing element.

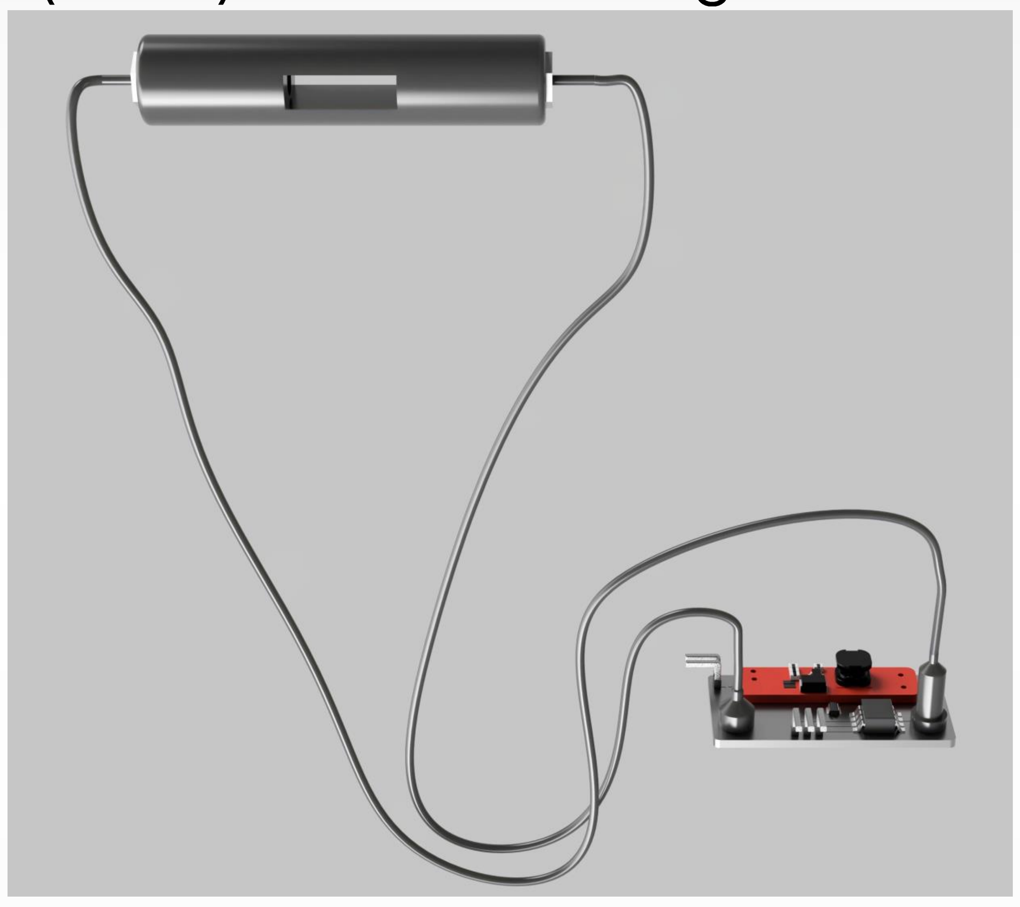

Figure 5: CAD render of improved design.

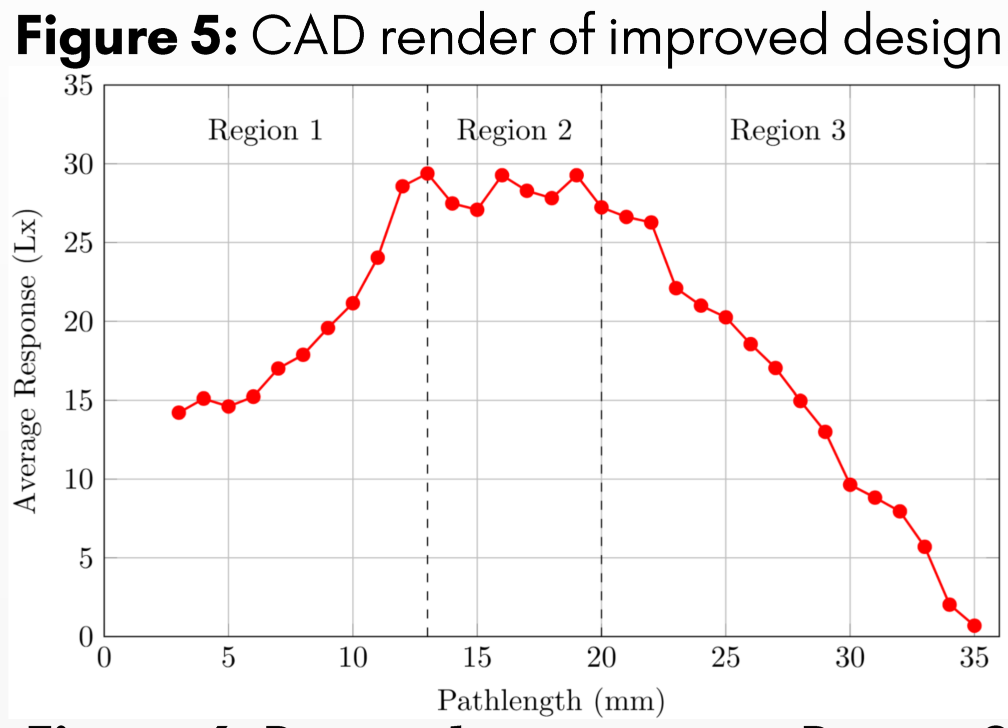

Figure 6: Region 1: converging. Region 2: collimated. Region 3: diverging.

Collimated pathlength ensures:

- No wasted incident light.
- Increasing bacterial cell contribution to absorbance reading.

The optimal pathlength was identified (**figure 6, Region 2**).

CLIMs :

- Enables dynamic sensitivity identification.
- Improved accuracy and sensitivity.
- Simplifies device by removing variable pathlength.

Custom Sensing Element

A transimpedance amplification (TIA) circuit (**figure 7**):

- Designed for silicon photodiode optimised for 780nm (**figure 8**).
- Fine-tuned sensing parameters for a reduced size.
- Output matches on-market hydroponic sensors.

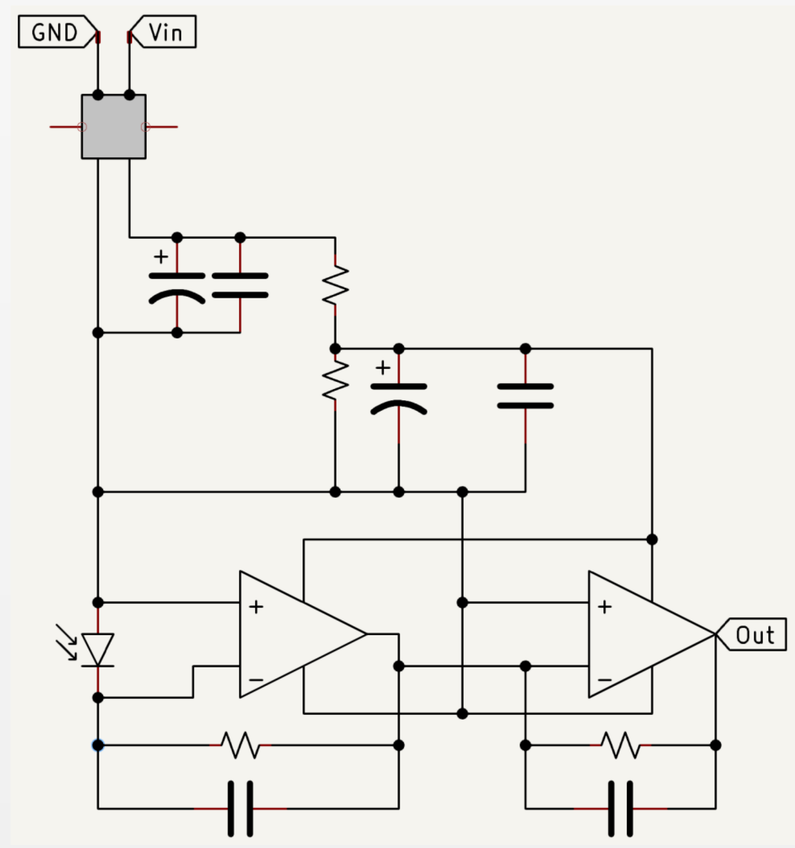

Figure 7: Dual-stage TIA circuit.

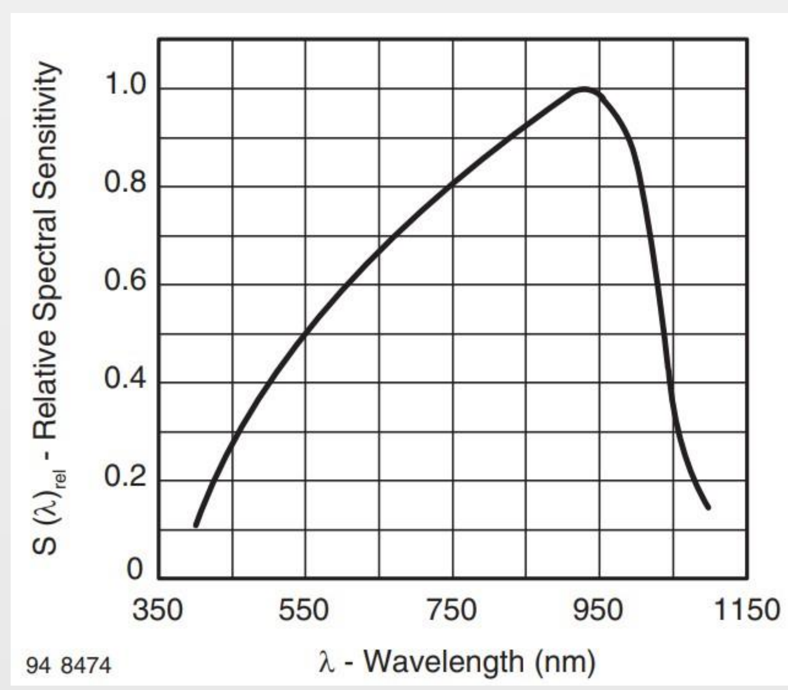

Figure 8: Si-photodiode sensitivity vs wavelength.

Post-Mortem Analysis

The device in **figure 1** featured at the Prototypes for Humanity Expo in Dubai (**figure 4**), attracting interest from academics and BioTech investors. It can run continuously, adjusting pathlength as culture density increases. Main limitations are:

1. 650nm LASER photopigment overlap
2. Relative size and weight
3. Coupling pathlength and optics

Conclusion

The sensor is a powerful and accessible tool for researchers and engineers, with:

- ***Higher accuracy***
- ***Higher data throughput***
- ***Reduced cost***
- ***Easier integration with reactors***

References

[1] L. S. R¨osner, F. Walter, C. Ude, G. T. John, and S. Beutel, "Sensors and techniques for on-line determination of cell viability in bioprocess monitoring," Bioengineering2022, Vol. 9, issn: 2306-5354.
[2] K. Drescher, J. Dunkel, L. H. Cisneros, et al., "Fluid dynamics and noise in bacte-rial cell-cell and cell-surface scattering," vol. 108, doi:10.1073/pnas.1019079108/-/DCSupplemental.
[3] T. Nieminen, D.F.P. Pile, N.R. Heckenber, "Multiple-scattering Modelling of Scattering by Biological Cells", Electromagnetic and Light Scattering-Theory and Applications VII., pp259-262.
[4] J. D. P. Peter Atkins, Atkins' Physical Chemistry, 8th ed. OUP Oxford, 2006,isbn: 10: 0198700725.
[5] W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes 3rd Edition: The Art of Scientific Computing. Cambridge University Press,2007, isbn: 0521880688.
[6] ams AG. "Tsl2591 lux sensor." (), [Online]. Available: https://learn.adafruit.com/adafruit-tsl2591/downloads. (accessed: 02.03.2024)