Development of Portable Spectrophotometer

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Introduction

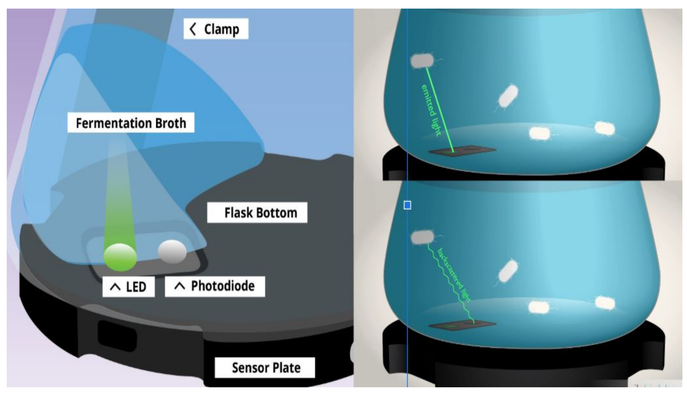
- Bioreactor system are vital for cultivation and growth of cells in laboratory, setting, particularly for biochemical engineering .
- Traditional bioreactor systems often face challenges in scalability, cost, and controlling the environmental factors that impact cell growth..
- Advancements in cell culture technology have led to improved methodologies, but there is still a gap in providing efficient and affordable systems for a wide range of applications, from stem cell research to biopharmaceutical manufacturing

Existing Work

- **Bulky Instrument**: Many existing systems rely on large and complex equipment that are difficult to integrate into compact or mobile environments.
- **Costly Instruments**:: High costs of instruments make them unaffordable for many organizations, limiting widespread adoption.
- **Low-Scale Implementation**: Many methods lack efficiency and reliability when applied beyond laboratory settings, limiting their practical use.

Working Principle

Our spectrophotometer operates on the principle of **light backscattering** to determine the **optical density (OD)** of a sample. When a collimated beam of light passes through the sample, a portion of it is scattered in various directions due to interactions with suspended particles or molecular structures. The **backscattered light**, which is reflected in the direction opposite to the incident beam, is collected by a detector positioned accordingly.



The intensity of this backscattered light is inversely related to the sample's optical density. By measuring the detected light intensity and applying a calibrated relationship, we compute the **optical density** using the Beer-Lambert Law analog for scattered light:

$$\mathrm{OD} = -\log_{10}\left(\frac{I}{I_0}\right)$$

- I = Intensity of backscattered light from the sample
- I_0 = Intensity from a reference

This method allows us to quantify turbidity or concentration in a non-invasive, cost-effective manner using our **custom-built spectrophotometer**.

Our Approach

We developed a compact, low-cost spectrophotometer for measuring OD600, crucial for tracking microbial growth. The system combines hardware and software to ensure portability, accuracy, and real-time data processing.

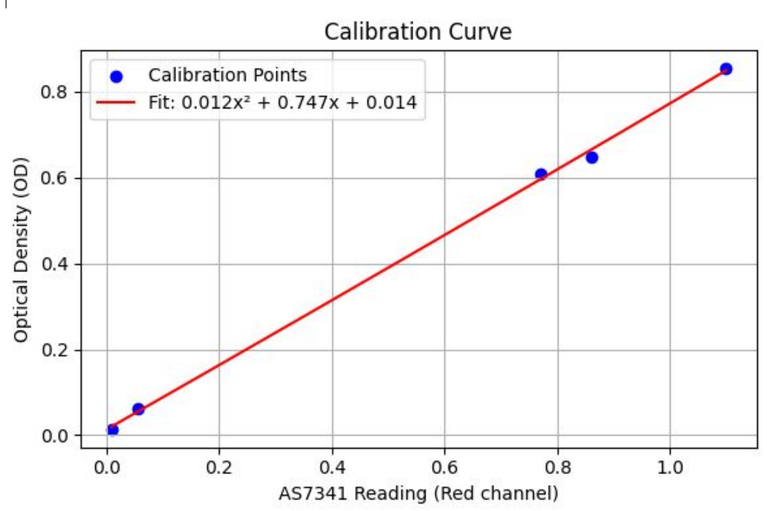
Hardware Integration:
The device uses the **M5StickC Plus2 microcontroller** with a built-in display, paired with two sensors:

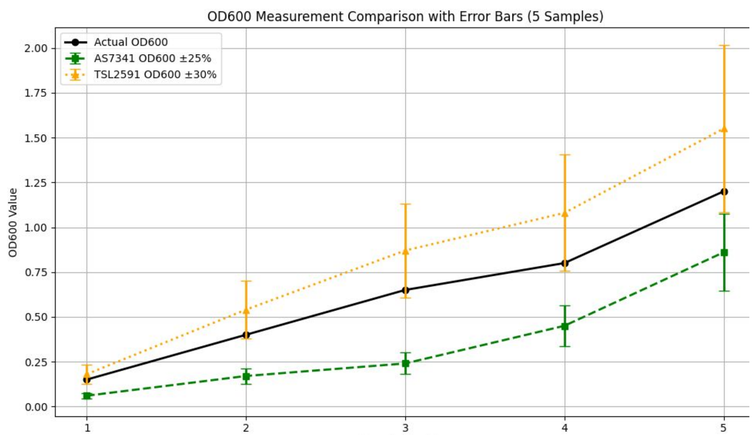
- **TSL2591:** High-resolution sensor ideal for 600 nm backscatter detection.
- **AS7341:** Multispectral sensor used for broad wavelength detection.

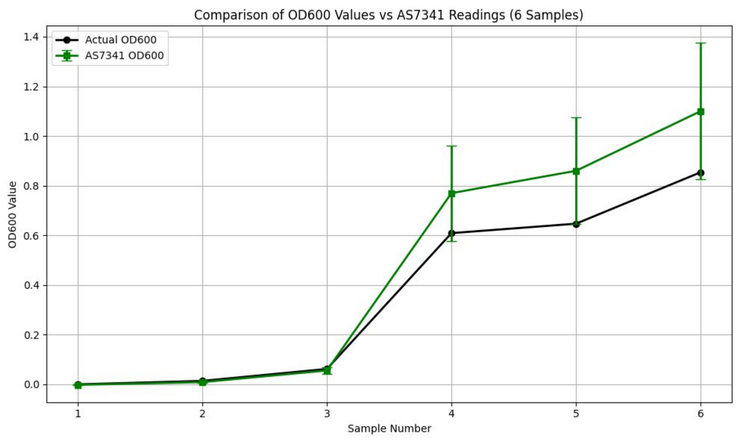
After resolving hardware communication issues, we established stable data flow between the microcontroller and sensors.

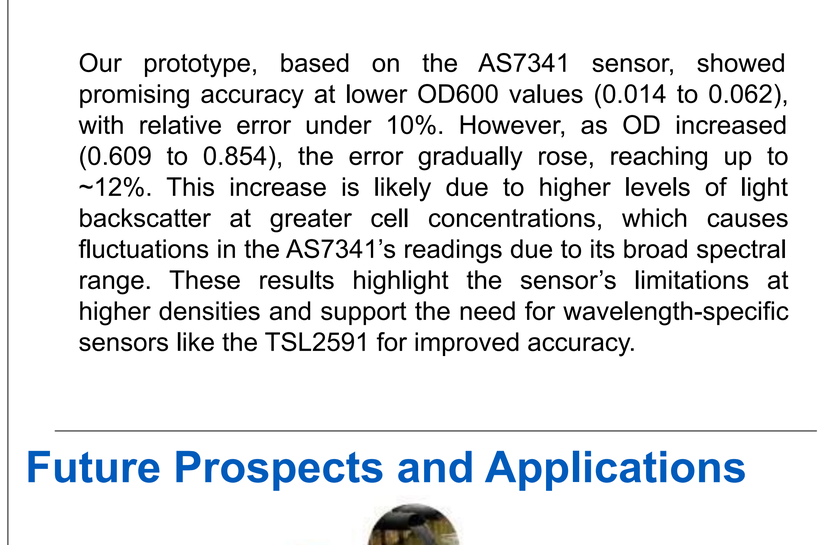
Software and Validation:
Using Python, we plotted real-time luminosity vs. time graphs and calculated OD values via a logarithmic formula (Beer-Lambert Law analog). We validated our readings by comparing them with a standard lab spectrophotometer to improve calibration accuracy.

Experimentation









Model Prototype

Results

OD600	AS7341	RELATIVE ERROR (%)
0.014	0.012	14.29
0.062	0.056	9.68
0.609	0.598	1.81
0.647	0.602	6.96
0.854	0.957	12.06

Our prototype, based on the AS7341 sensor, showed promising accuracy at lower OD600 values (0.014 to 0.062), with relative error under 10%. However, as OD increased (0.609 to 0.854), the error gradually rose, reaching up to ~12%. This increase is likely due to higher levels of light backscatter at greater cell concentrations, which causes fluctuations in the AS7341's readings due to its broad spectral range. These results highlight the sensor's limitations at higher densities and support the need for wavelength-specific sensors like the TSL2591 for improved accuracy.

Future Prospects and Applications

- Future versions will support multispectral measurements (e.g., OD260/280) for biomolecule quantification, along with miniaturization for portability. This makes the device suitable for resource-limited environments.
- Integration of real-time wireless data logging and cloud storage will enhance monitoring capabilities. Onboard AI-based analysis can enable automatic detection of microbial growth phases and flag anomalies during culture development.
- The device is envisioned as a cost-effective alternative for microbial growth tracking, fermentation optimization, and biosensor-based diagnostics. It also serves as a valuable teaching tool for microbiology and biotechnology education.

Acknowledgements

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