Multispectral Imaging for Agricultural and Environmental Monitoring

Minutes to Meaning with 13-Band Multispectral Imaging

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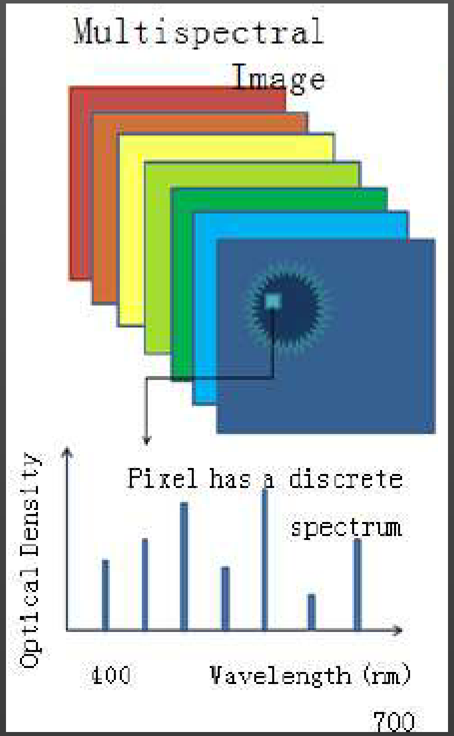
Deep Vision. Bright Future

Multispectral Imaging (MSI)

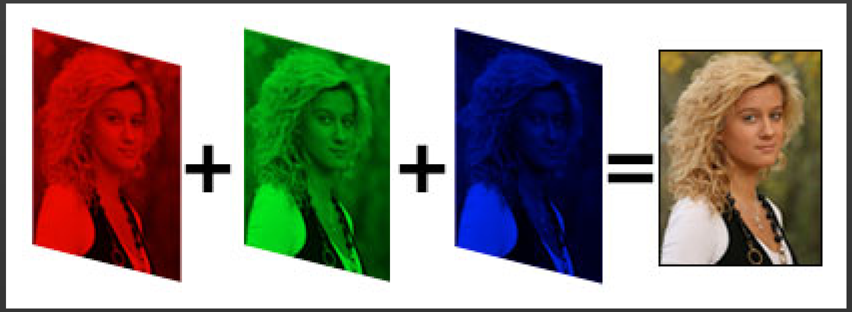
What is MSI?

- A technique for capturing and processing images across multiple wavelengths.
- These wavelengths extend across the electromagnetic spectrum, exceeding the human vision range.
- This technique has applications across fields such as agriculture, surveillance, and remote sensing.

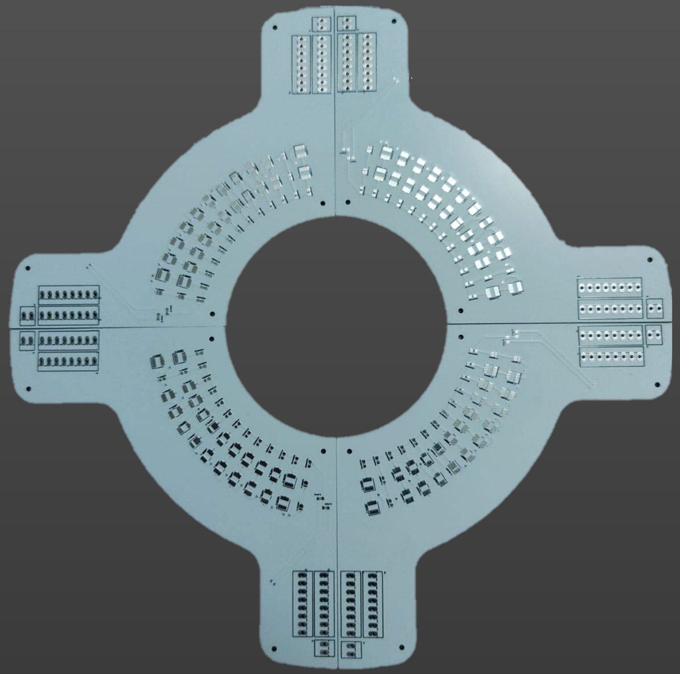


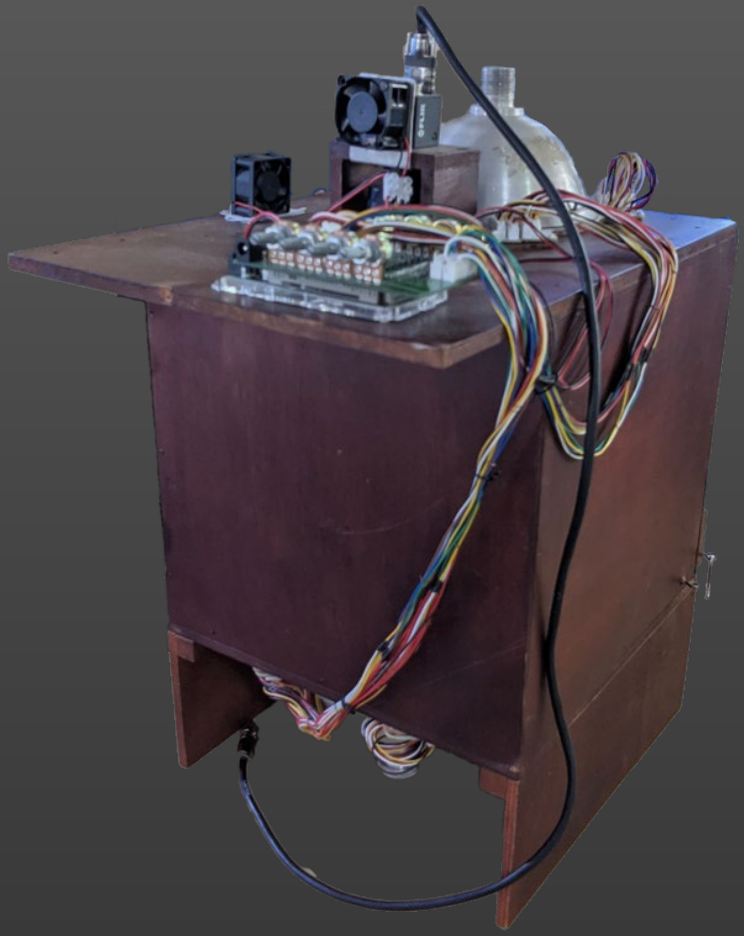
Why MSI over RGB?

- The availability of multiple spectral bands in MSI images enables the application of advanced image processing and analysis techniques.
- With MSI, it is possible to distinguish between different materials or objects based on their spectral signatures. By analyzing the data in specific spectral bands, it becomes easier to identify and differentiate objects that may appear similar in RGB images



Imaging System

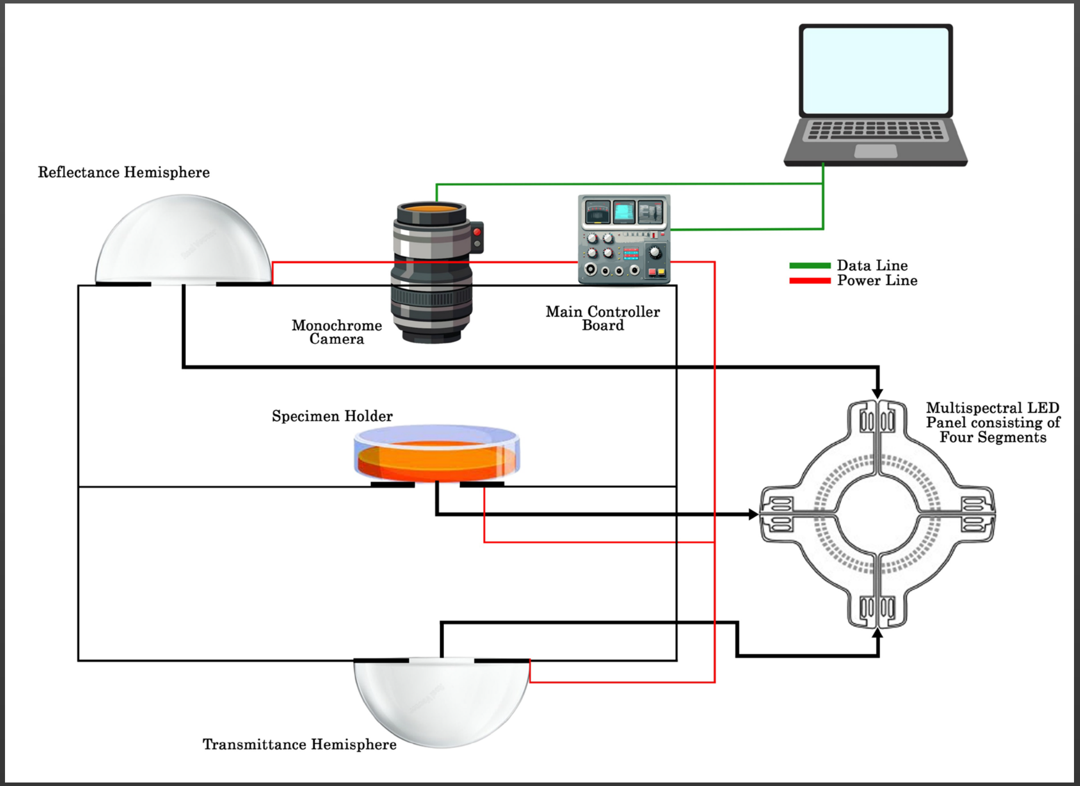




13 bands • mono camera • modular panels • GUI

Features of the System

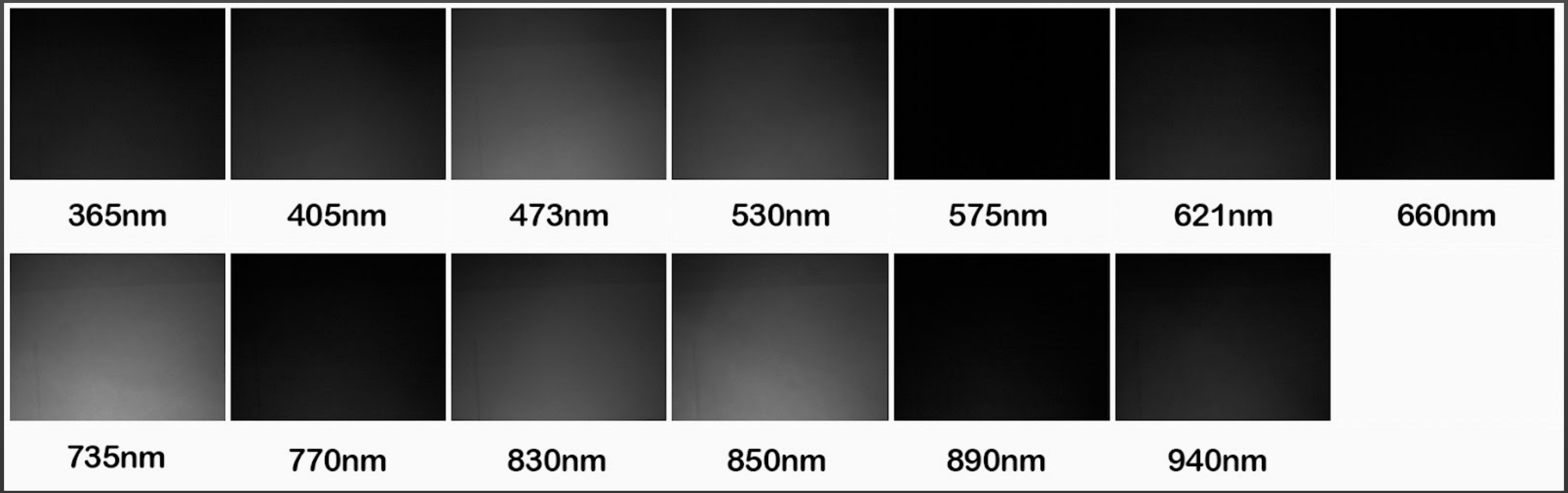
- Dual mode operation (Reflectance and Transmittance)
- Modular Architecture
- Industrial-grade monochrome camera
- Graphical User Interface (GUI)



Assessment of the System

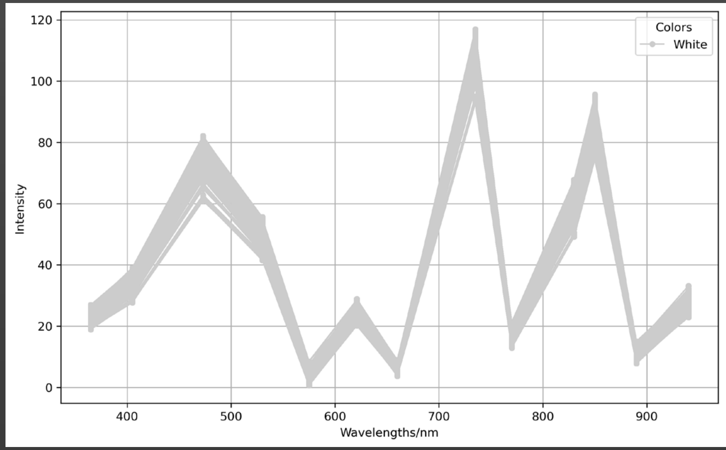
Evaluation of Intensity Variation

- To evaluate the uniformity of light intensity captured by the MSI device, images of a plain white paper were taken across the wavelengths of the system

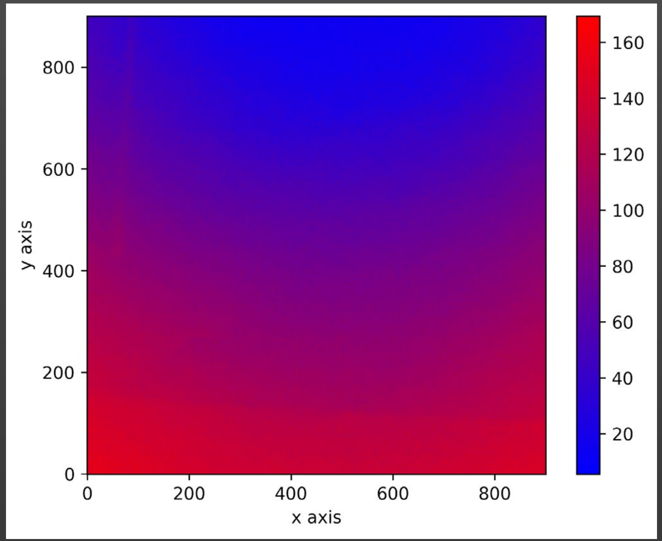


Evaluation of Intensity Variation

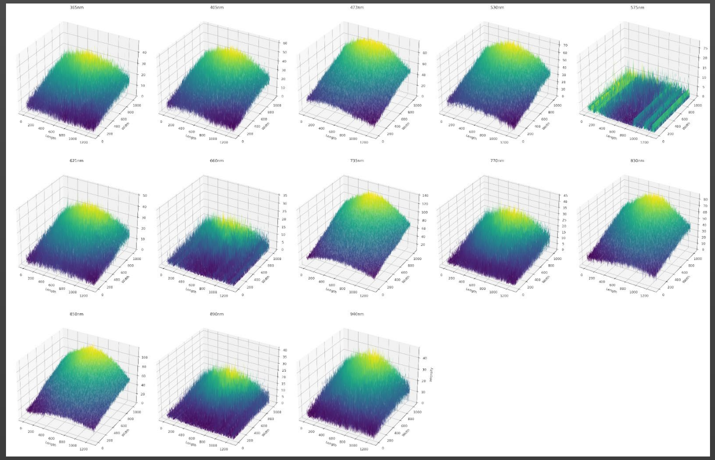
- Two main inconsistencies observed
  1. Average intensities vary with the wavelength
  2. The intensities are not uniform across the image area
- For further analysis, the variation of intensities across wavelengths and image area was visualized.



Spectral Signature of the White Paper Image



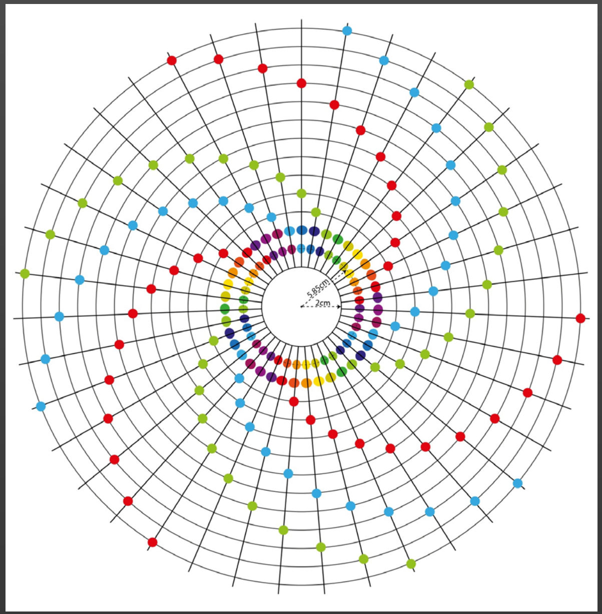
Spatial variation of the Euclidean distance of the spectral signatures with respect to the center pixel of the highest illumination region when imaging a white paper.



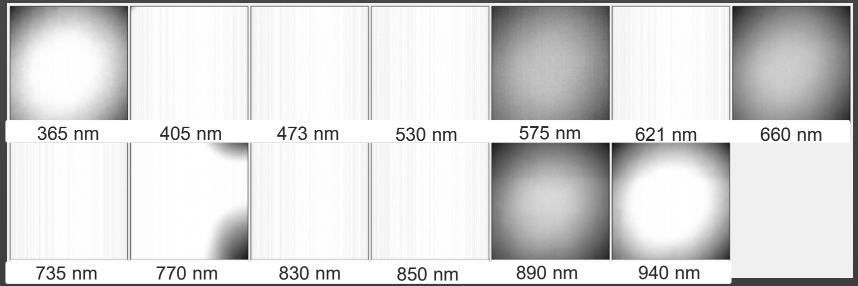
3D Surface Plot of Intensity Variations across all Wavelengths

Optimizing LED Arrangement

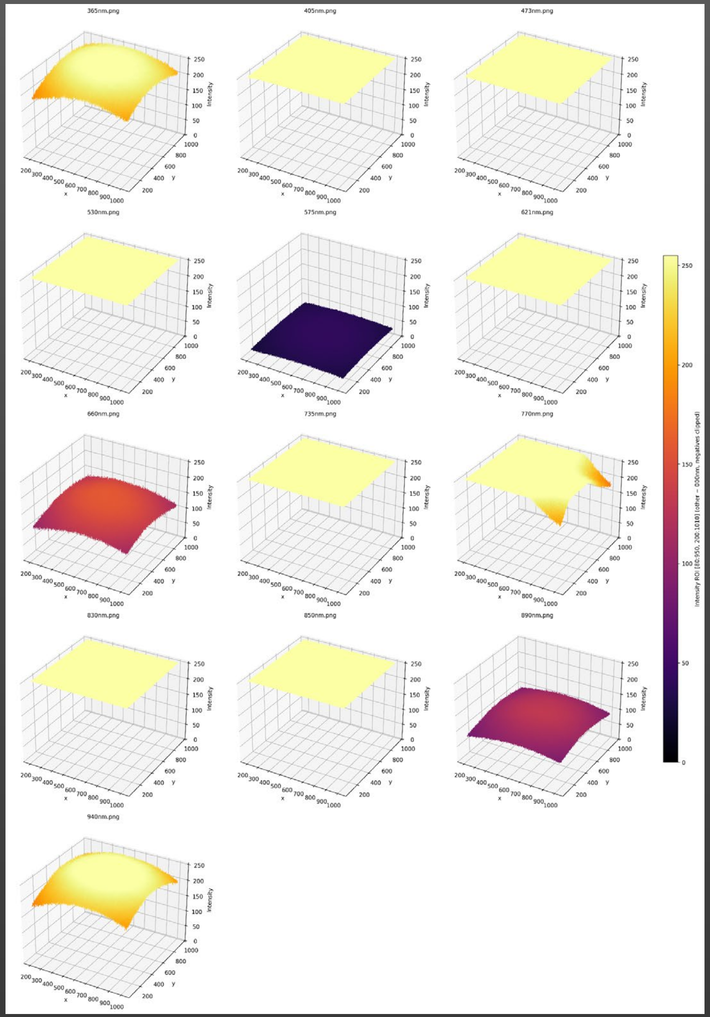
- Different LED arrangements tested
- Reflectance and Transmittance setups



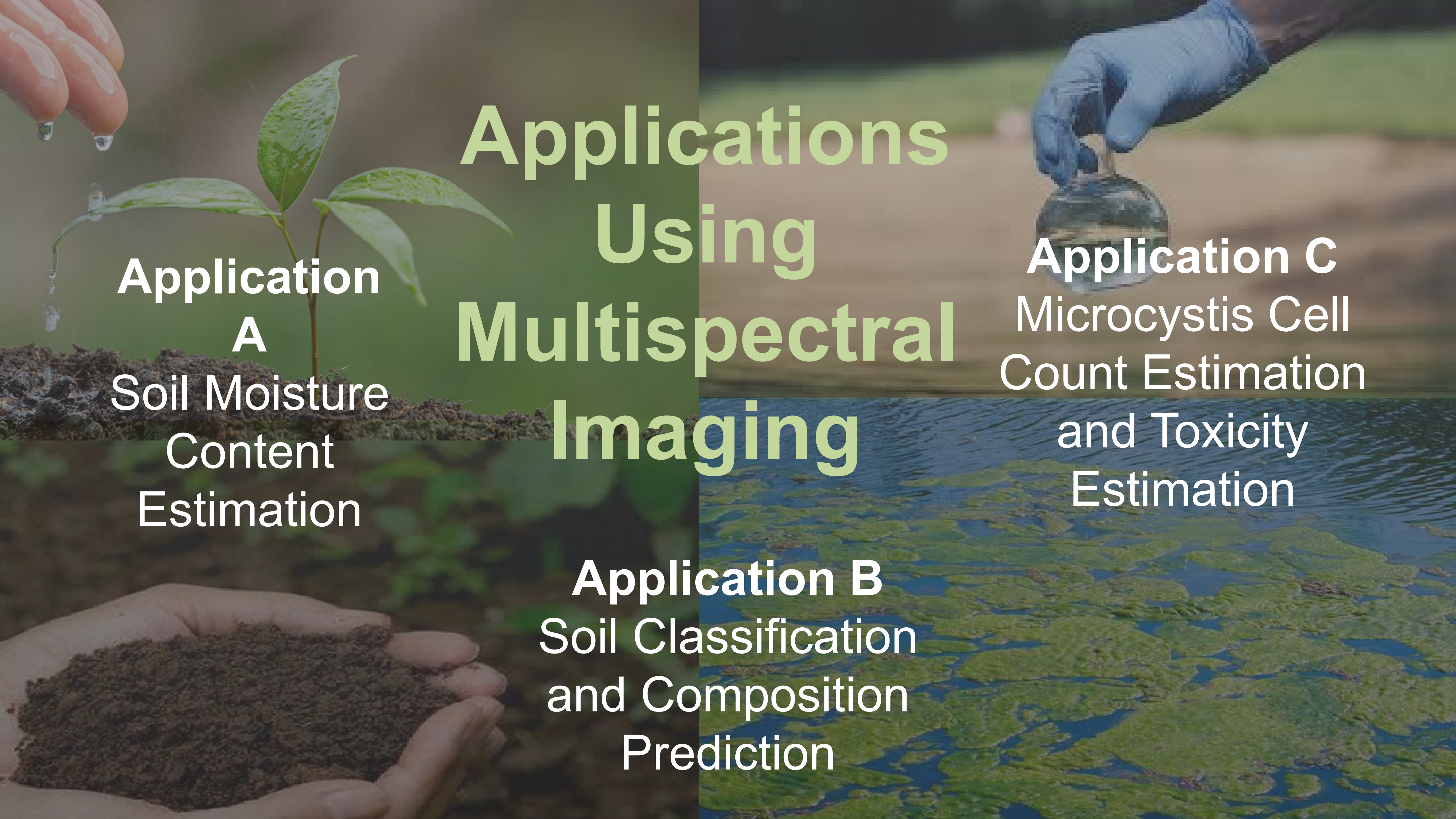
Selected three spiral design



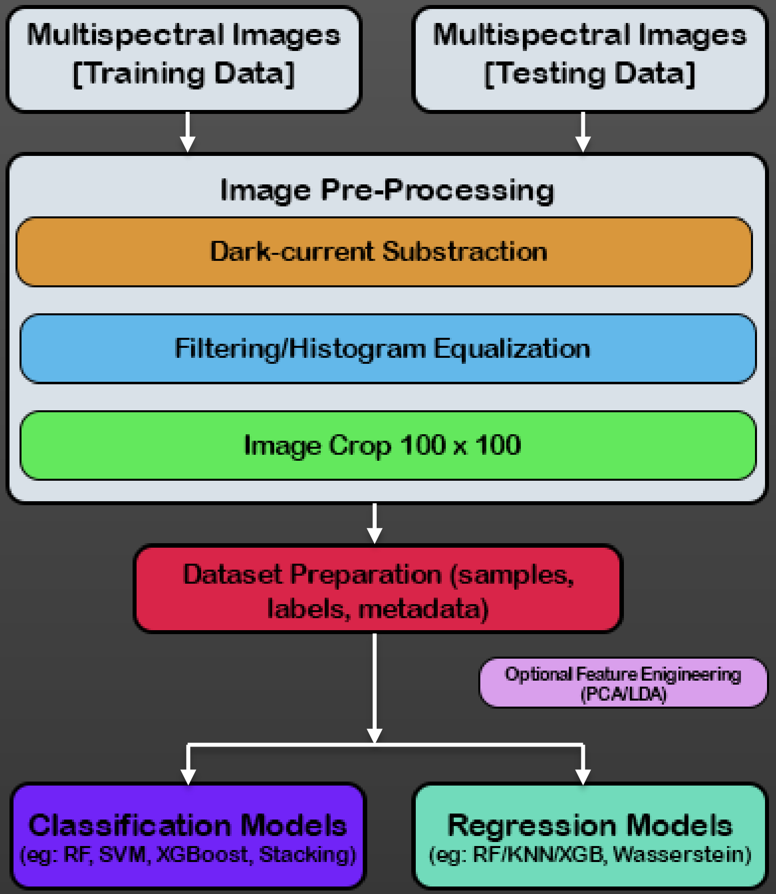
Images of a white A4 sheet with new LED arrangement

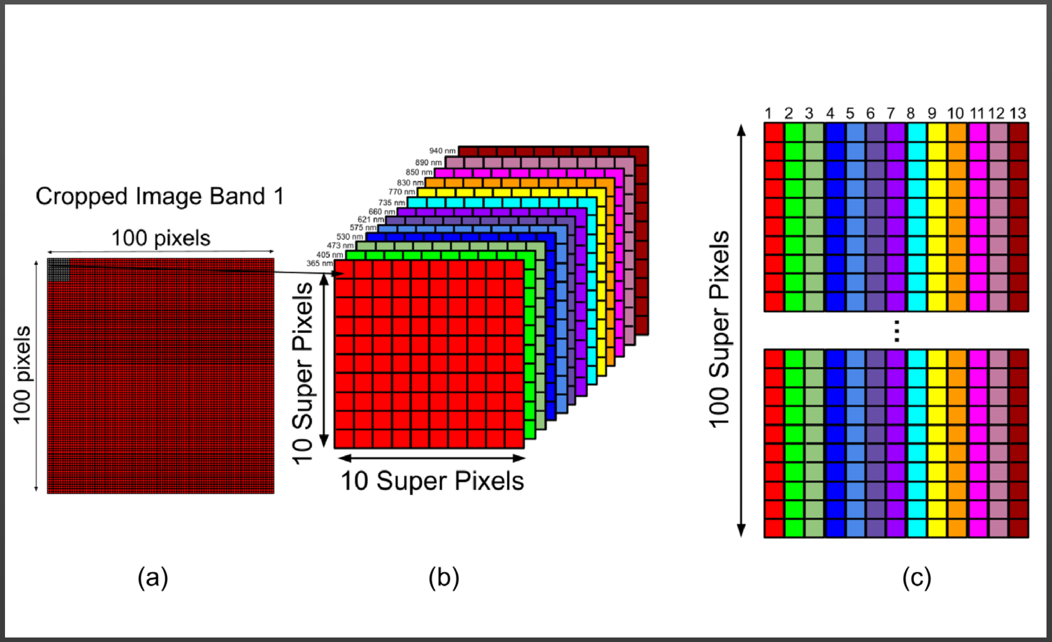


3D Surface Plot of Intensity Variations across all Wavelengths


Applications Using Multispectral Imaging
Application A
Soil Moisture Content Estimation
Application B
Soil Classification and Composition Prediction
Application C
Microcystis Cell Count Estimation and Toxicity Estimation

The Common Pipeline for Methodology





Application A – Soil Moisture Content Estimation

Soil Moisture Content Estimation

Agriculture and Crop Management

- Helps determine the right timing and amount of water to apply, avoiding over-irrigation or water stress.
- Ensures plants receive adequate moisture for optimal growth and yield.

Civil Engineering

- Helps assess soil stability and strength for construction projects.
- Identifies areas prone to landslides based on soil saturation levels.

Available Methods & Limitations

There are two primary approaches for estimating SMC: indirect methods and direct methods.

Available methods	**Limitations**
Oven dry method	Time consuming , Labor-intensive nature
Neutron scattering method	Require highly specialized and expensive equipments. the risk of health hazards for operators with continued use.
Gamma attenuation method	
Resistive sensors	Require calibration at each location of application which could be highly time-consuming
Time domain Reflectometry(TDR) sensors	
Frequency Domain Reflectometry (FDR) sensors	

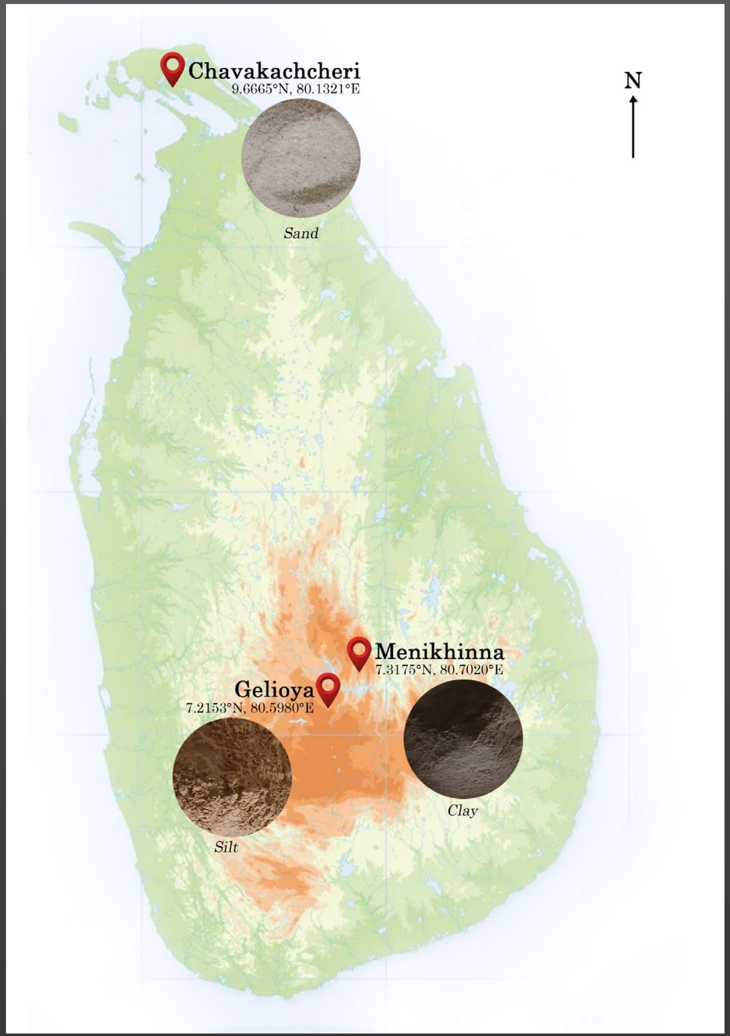
Recently, multispectral or hyperspectral imaging has emerged as an excellent analysis method due to its non-destructive and non-invasive capabilities.

Sample Preparation

- Soil Samples
  - Silt
  - Clay
  - Sand
- Procedure
  - Remove large particles (stones etc.) from each sample and sieve with 2mm sieve
  - Add water and keep till saturation (~24 h)
  - Take 5 soil specimens from each soil type
  - Capture initial image
  - Oven-dry samples for 5 min and capture images
  - Repeat till fully dried

Soil specimens

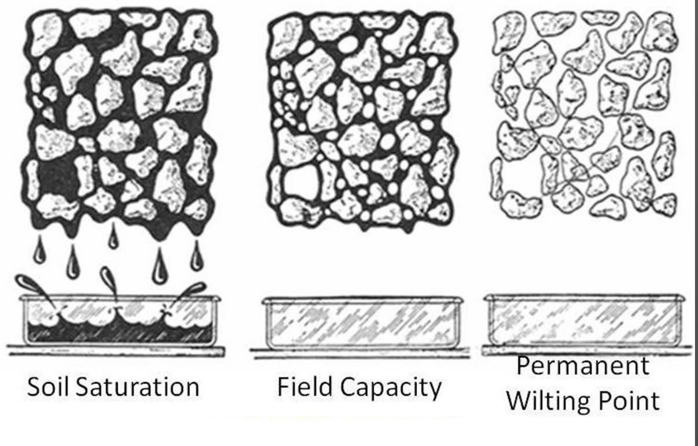
$$I_{correct} = \left(avg - \frac{std}{2}\right) + std \cdot \frac{\tanh\left(0.04 \cdot \left(I_{crop} - avg\right) + 1\right)}{2}$$

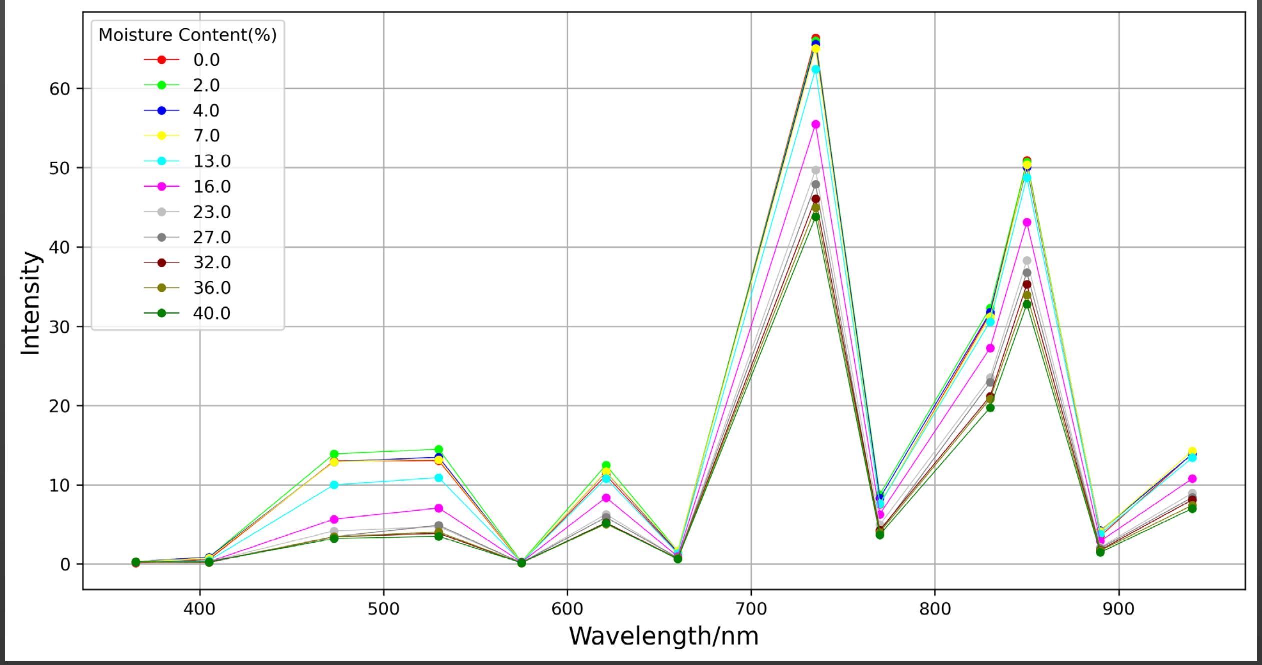


Soil sample collection areas

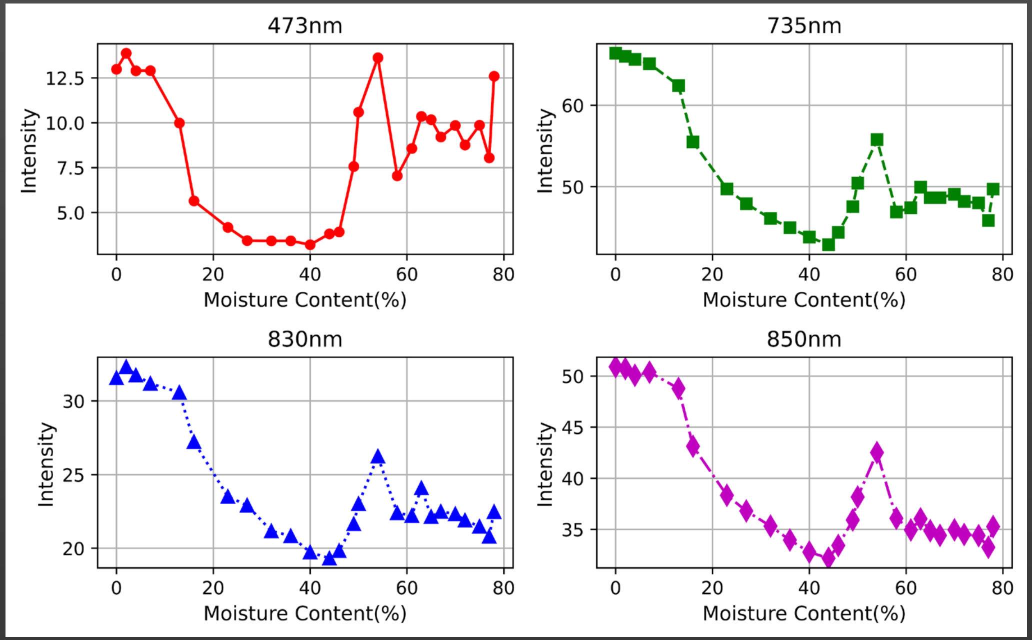
Results

- Spectral Signature
  - Intensity (Y-axis) vs. Moisture Content (X-axis)



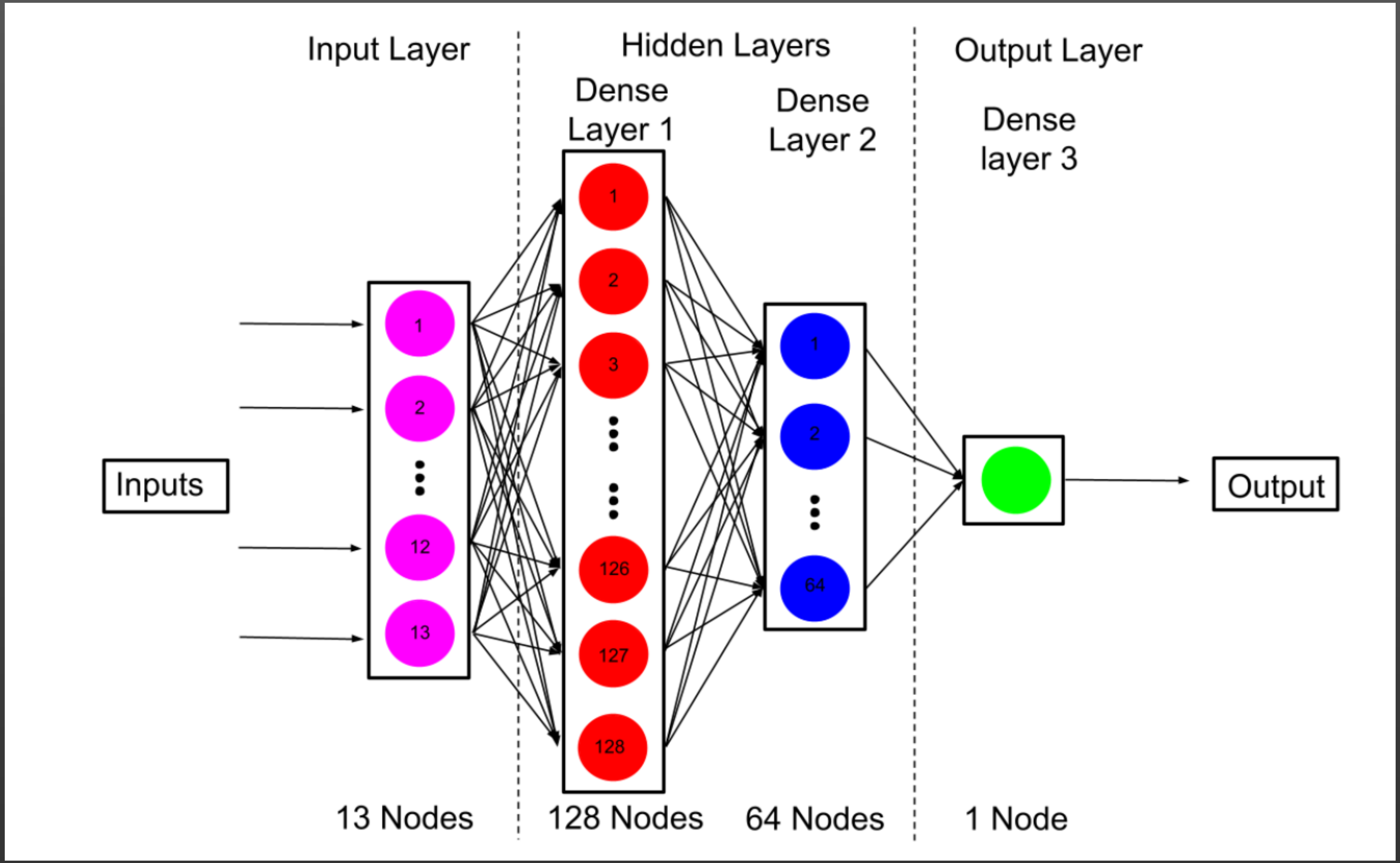


Spectral signature of silt soil

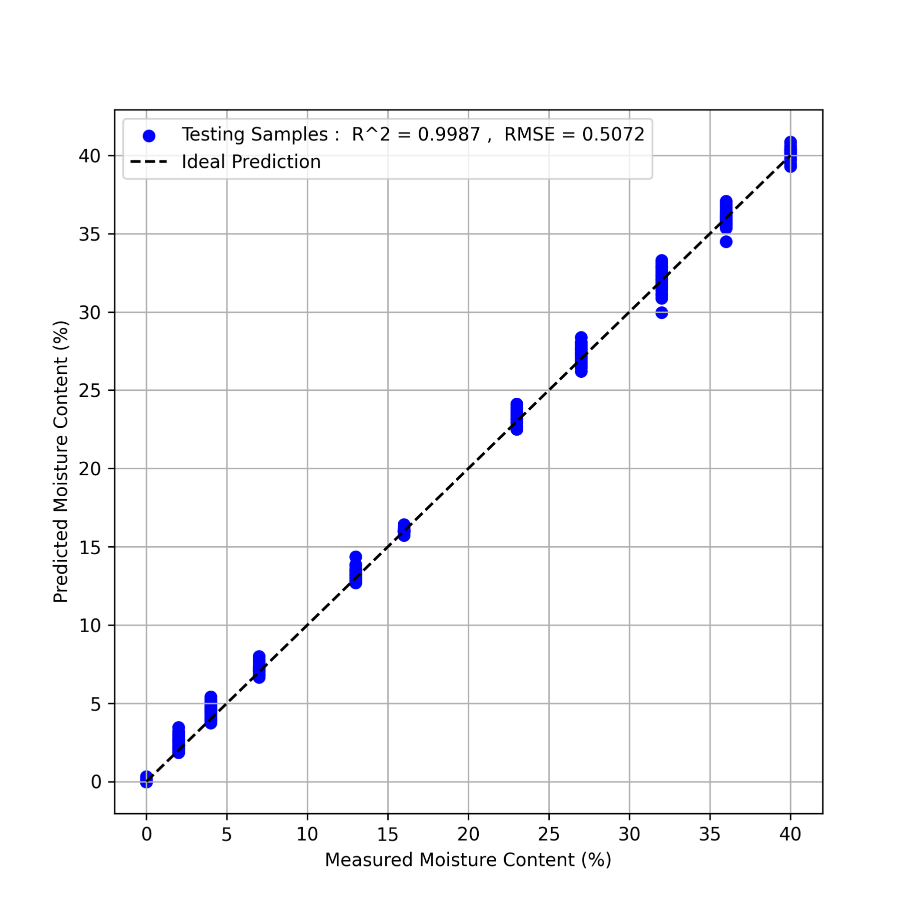


Intensity vs. Water Content at 473nm, 735nm, 830nm, and 850nm for Silt Soil

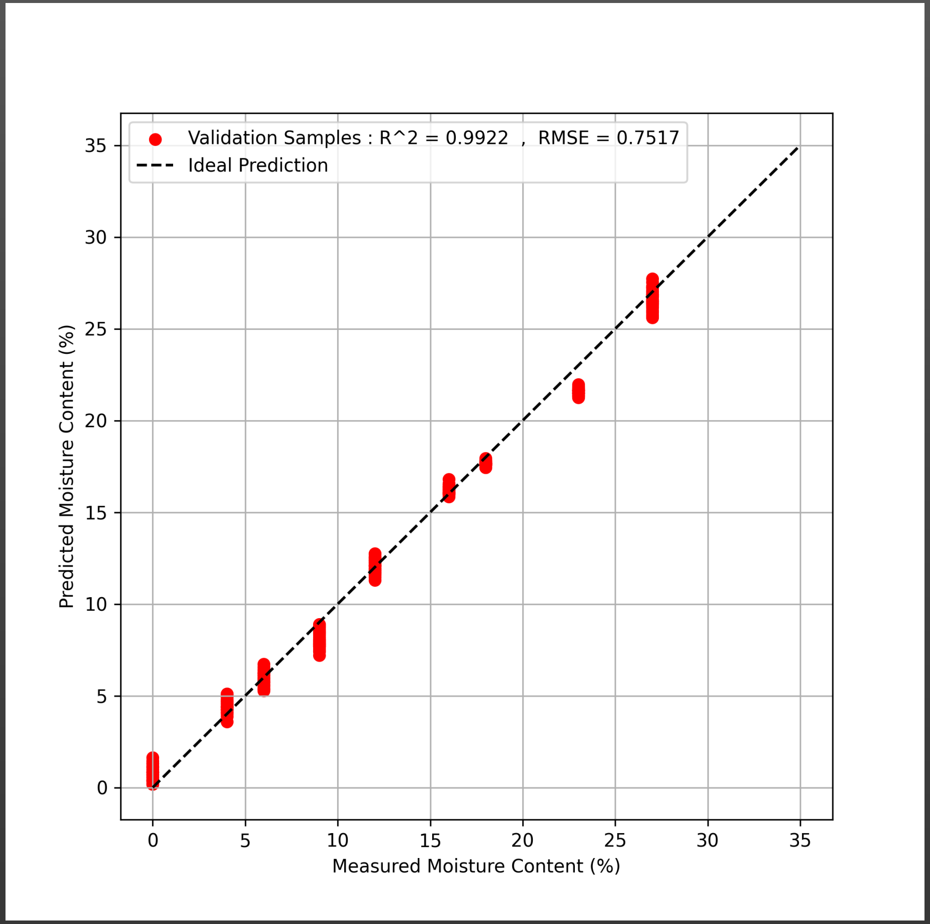
Four Layer Fully Connected Neural Network



Regression Analysis



R^2 = 0.9987 RMSE = 0.5072



R^2 = 0.9922 RMSE = 0.7517

Publication

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Deep Learning for Soil Moisture Content Estimation via Reflectance Multispectral Imaging

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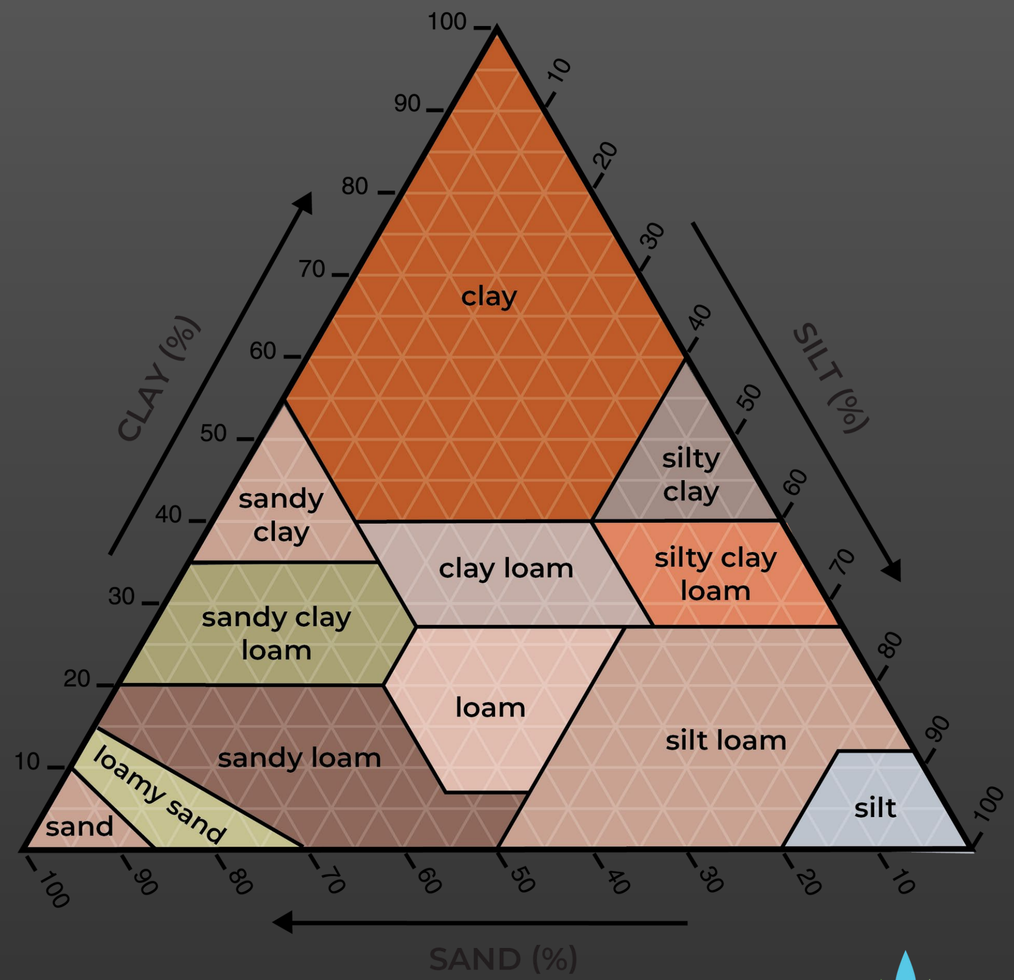
Application B – Soil Classification and Composition Prediction

Fundamental Soil Types (USDA)



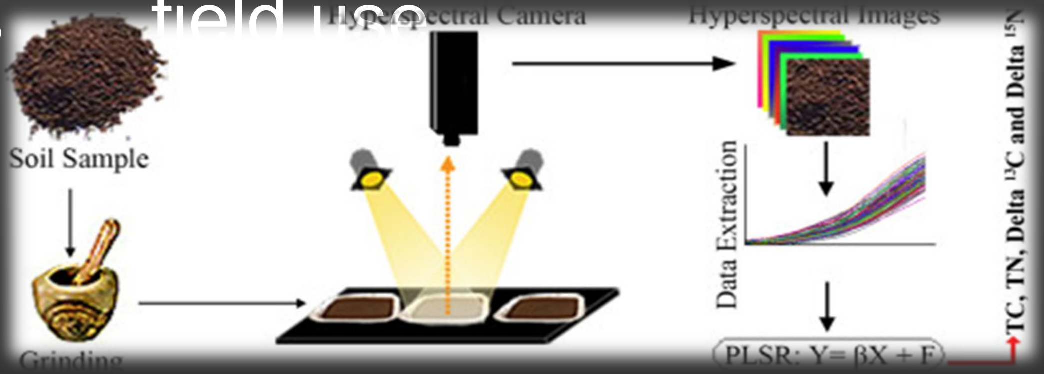
Soil Classification Techniques

Classical Laboratory Methods

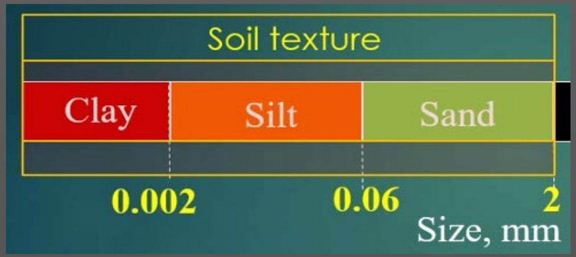
- Hydrometer / pipette analysis yields sand, silt, clay fractions accurately
- Highly accurate, standardized by USDA, but slow (hours–days) and requires chemicals

Imaging-Based Methods (HIS/MSI)

- HSI (hundreds of bands): Accurate, but expensive and data-heavy
- MSI (fewer bands): portable and low-cost, suited for in-field use



Generating Data



Obtaining Pure Soil

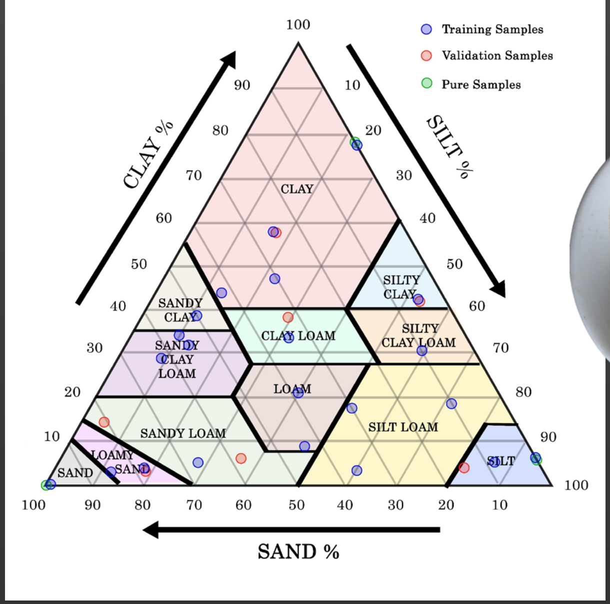
- To create datasets of various compositions, ideally pure samples of all 3 fundamental types were required.
- However, this was not practically viable as soil always exists in nature as a mixture of these fundamental types.
- To alleviate this, with the aid of the Civil Engineering department, soil samples of relatively high purity were obtained.
- However, before capturing MSI images, the actual compositions of the "pure" samples needed to be verified using lab tests

Creating Textures

- From the laboratory tests, the compositions of "pure" samples were as follows.
  - Clay – (Clay = 79%, Silt = 19%, Sand = 2%)
  - Silt – (Clay = 6%, Silt = 91%, Sand = 3%)
  - Sand – (Clay = 0%, Silt = 0%, Sand = 99%)
- After obtaining these values, mixtures of the three "pure" samples were created so that all soil types in the USDA texture triangle were well represented.

Calculating Composition

- Two main laboratory tests are performed to calculate the composition based on particle size.
  - Sieve Analysis
  - Hydrometer Analysis

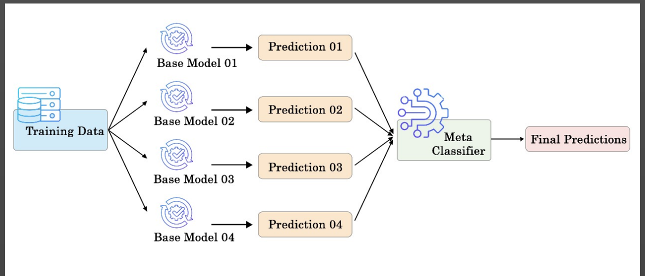


Results for Soil Classification

- Different machine learning models was used for soil type classification.

Classification model	Accuracy (%)
K-Nearest Neighbors	96
Random Forest	97
Support Vector Machine	86
Decision Tree	93
Gradient Boosting	95

- To further improve the results stacking method was used by using the models with accuracies exceeding 90% as base models.



Structure of Stacking Method

Meta model	Accuarcy (%)
K- Nearest Neighbors	97
Random Forest	98
Decision Tree	97
Gradient Boosting	97

Results for Soil Composition Prediction

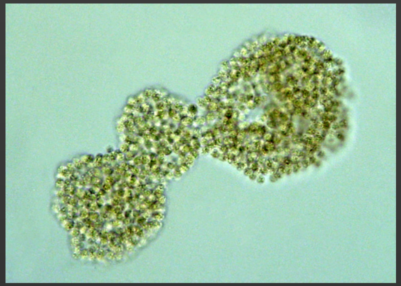
- To predict the soil composition (Clay, Sand, Silt percentages), different multi-output regressors were used.

Model	Clay		Sand		Silt	
	R2	RMSE	R2	RMSE	R2	RMSE
Random Forest	0.9804	2.8454	0.9727	4.4856	0.9854	3.1806
K-Nearest Neighbors	0.9792	2.9225	0.9625	5.2582	0.9761	4.0705
Decision Tree	0.9502	4.5391	0.9349	6.9358	0.9663	4.8321
XGBoost	0.9737	3.2995	0.9657	5.0299	0.9817	3.5583

Application C – Microcystis Cell Count Estimation & Toxicity Estimation

Microcystis Detection

- Our goal: Extend MSI to water quality via detecting Microcystis aeruginosa
- Why it matters: Causes toxic algal blooms in water – threat to humans & environment
- MSI = fast, low-cost alternative to chemical or microscopic tests



Traditional vs Modern Approaches

Toxicity & Growth Detection

- Toxicity
  - HPLC, ELISA
  - PCR for mcyE gene
- Growth
  - OD_{750}
  - Microscopy / Cell count

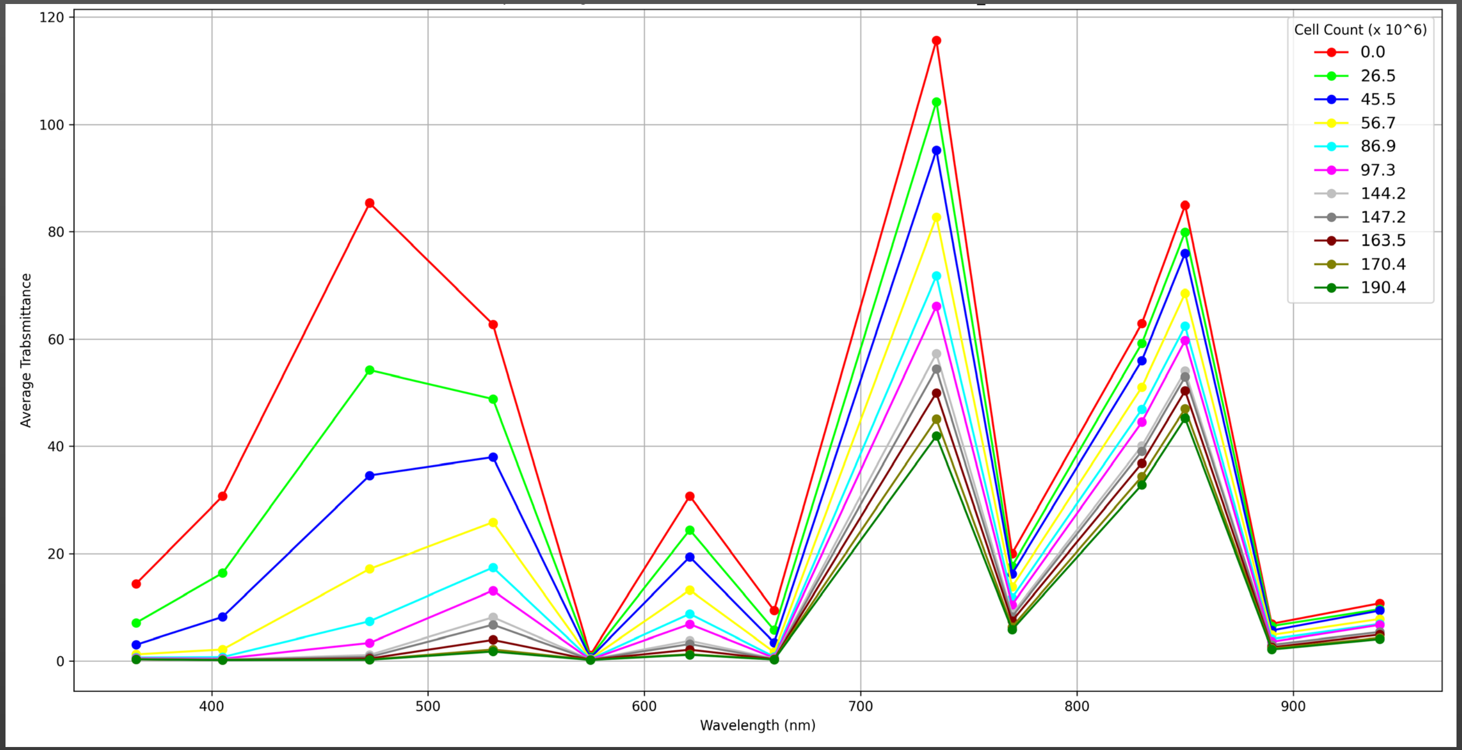
Remote Sensing & MSI/HIS

- Satellites: Sentinel-2, MODIS
  - ABDI, CI_{cyan}, NDVI, FAI

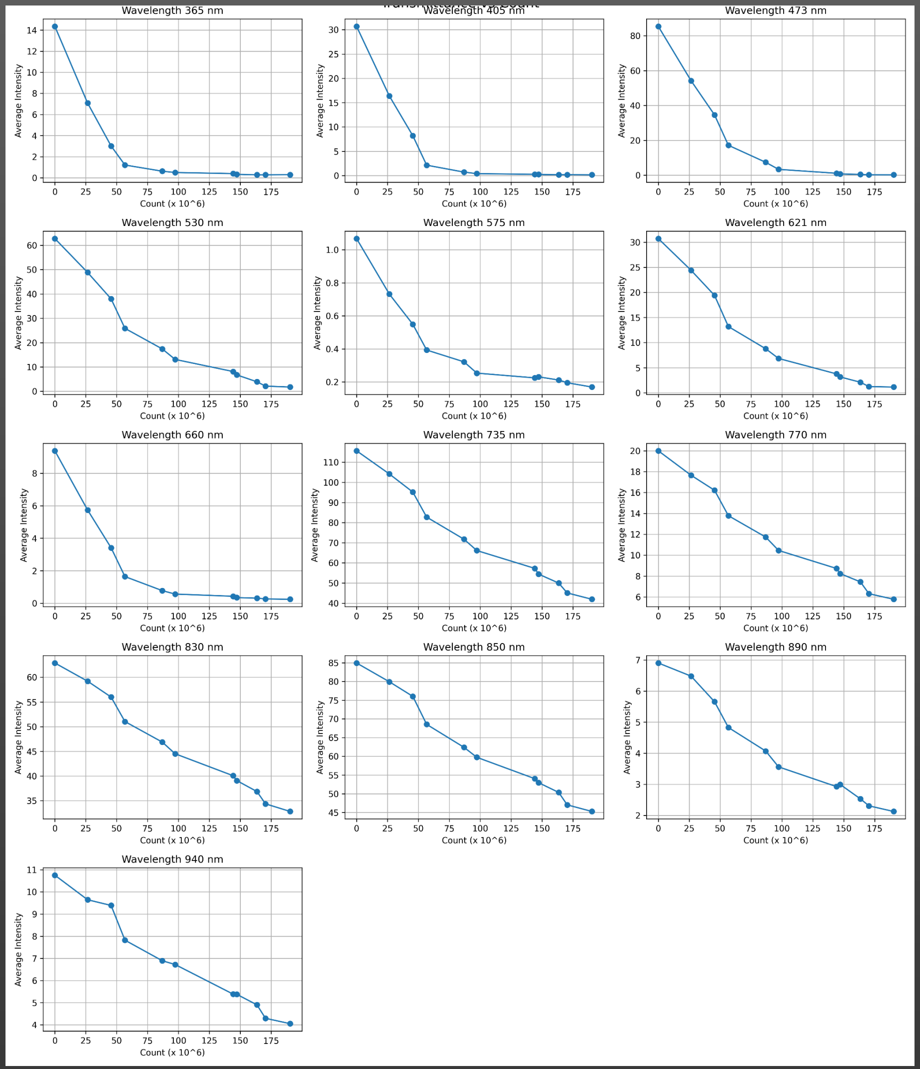
Samples

- **Sample**: Collect Kandy Lake water; cool, dark transport.
- **Confirm & isolate**: Microscope check; pick Microcystis colonies into sterile M8.
- **Starter grow**: M8, ~25 °C, 12:12 L:D, gentle aeration.
- **Scale-up**: Transfer exponential culture to custom M8 tank; controlled light/mixing.

Results



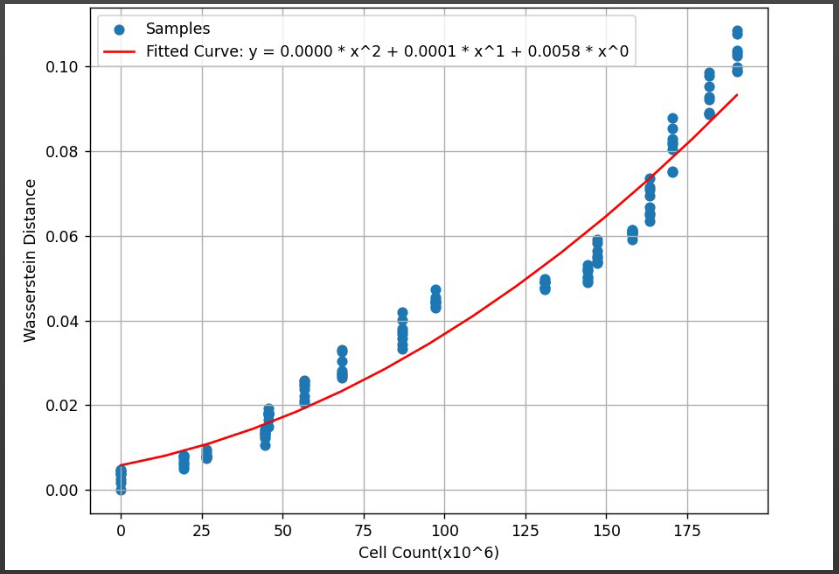
Spectral signature of different cell counts



Transmittance vs count

Results for Cell Count Estimation

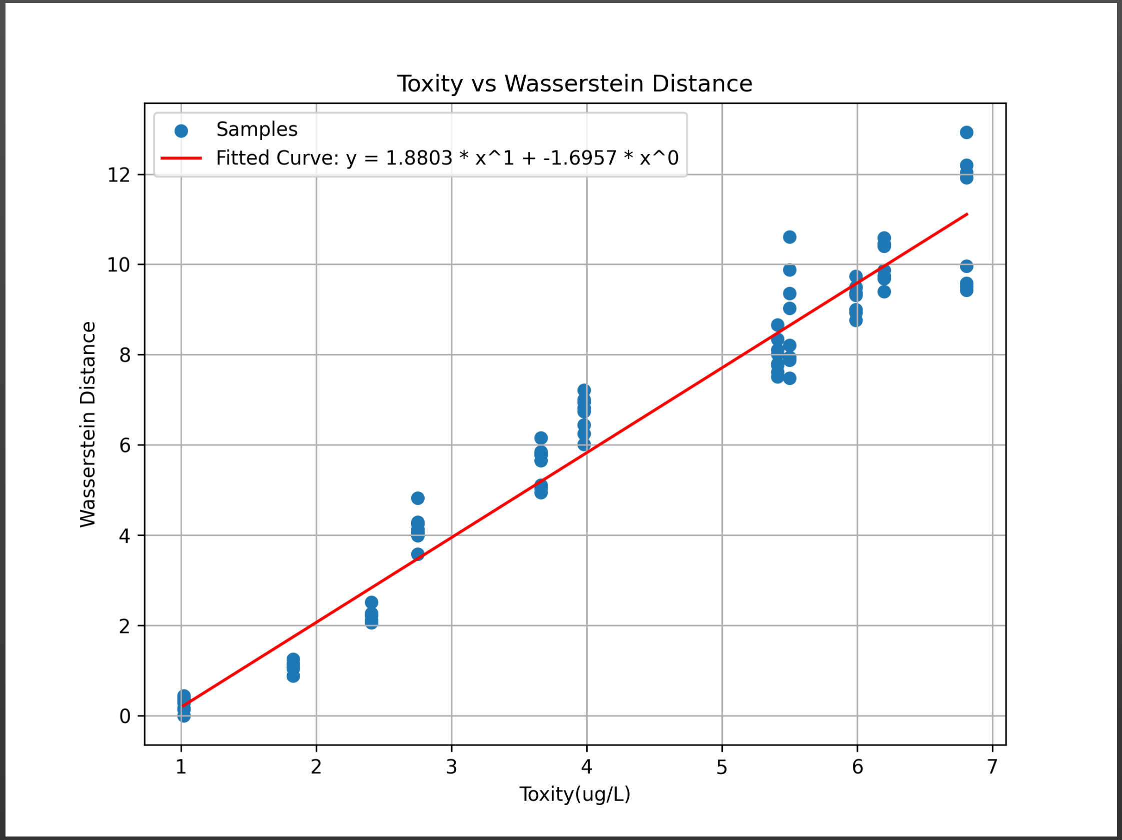
- Wasserstein distance shows similarity between predicted and actual distributions.
- **R^2 = 0.96 RMSE = 2.34**
- Strong correlation between predicted and actual cell counts

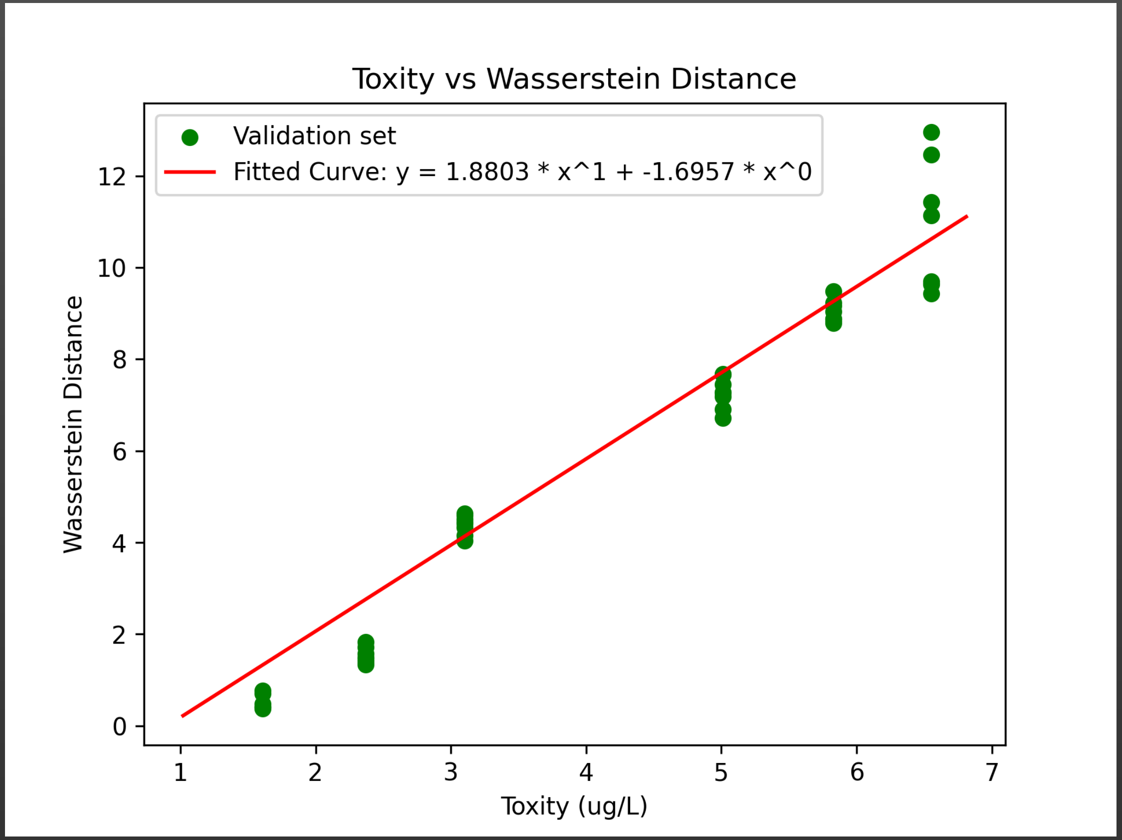


Wasserstein distance vs Cell count

Results for Toxicity Estimation

- **Training: R^2 = 0.96 RMSE = 0.7614**
- **Validation: R^2 = 0.95 RMSE = 0.8690**
- Strong correlation between predicted and actual toxicity





Ongoing Work

- Detecting Cassia Adulteration in Ceylon Cinnamon
- Detecting Palm-Oil Adulteration in Dairy Milk Fat
- Chilli Powder Adulteration: Detection and Quantification

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Thank You!