Title
Imagers as Sensors: Correlating Plant CO2 Uptake with Digital Visible-Light Imagery

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Imagers as sensors: Correlating plant CO₂ uptake with digital visible-light imagery

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Introduction: Use imagers to predict hard-to-measure natural phenomena

Some phenomena are difficult to measure

• Existing sensors are hard to use in the field
  Measuring some biological phenomena require bulky or invasive sensors which make deployments difficult to manage and increase experimental error.

• More creative sensing techniques are required
  These issues suggest the use of a model based on other sensing modalities which can provide sufficiently accurate prediction as a substitute for direct measurement.

Imagers are an untapped sensing modality

• Domain knowledge can suggest meaningful ways to process images of a given biological phenomena
  Biologists know which signals are important for understanding a particular phenomena. This domain specific knowledge can be codified into a set of image features which we can compute.

• Models based on image features turn imagers into first-class biological sensors
  These models can predict ground-truth that isn’t readily apparent from the images, a technique we call applied vision. Unlike general vision, the ground-truth is not easily recognizable by humans.

Problem Description: Estimating CO₂ uptake of a drought tolerant moss from images

Field measurement of CO₂ uptake is bulky and invasive

• What is CO₂ uptake?
  CO₂ uptake (µmol/m²/sec) is the amount of CO₂ absorbed or released by a plant during photosynthesis. Domain knowledge suggests that the greenness of the plant should be a good predictor of CO₂ uptake.

• Why is CO₂ uptake important?
  Dense measurement of plant CO₂ uptake can be extrapolated to entire forests. Such measurements can be used to refine the model of the global carbon cycle.

Experimental Setup

• Water the moss and cycle light source on and off
  Simulate a rain event and subsequent days and nights. The moss dries as water evaporates; during darkness, the water is redistributed. When dry throughout, the moss becomes dormant.

• Measure CO₂ uptake using spectroscopy
  Moss samples are kept in a controlled environment (left top), intake and exhaust air’s CO₂ contents is measured (left bottom). Labeled graph of CO₂ uptake from one drying cycle shown to the right.

Proposed Solution: Build statistical models from ground truth data gathered in the lab

Building sensing imagers

Start with images taken of a biological event stored in a database

Compute domain relevant image feature set

Find the most correlated image features and generate a model from this set to predict the biological event

Regression based model

Build a regression tree by recursively choosing a feature and corresponding threshold such that examples in child nodes have increased purity (resulting tree on right). Creates variable sized pseudo-bands based on the data.

Classification based model

• Training
  Divide range of values into six equal-sized bands and train six binary SVM based classifiers using all generated features.

• Prediction
  A point P is in class K if the Kth binary classifier responds most strongly (table to the left). A classified point P is assigned the median value of class K.

Prediction accuracy

Classification based model

Explanation of error

- too few classes to cover all drying states
- many classes had too little training data
- classes of fixed size, doesn’t reflect reality

Regression based model

Better prediction

- nine (9) “bands” chosen intelligently
- “bands” are data adaptive rather than static

Extracted Features

• Domain knowledge suggests that color, specifically greenness, is a good predictor
  • Compute HSV (Hue, Saturation, Value) histogram
    - more stable than RGB
    - inexpensive to compute
  • Compute a set of variable sized windows, grouping similar colors (right bottom)

Error analysis

• Likely locations of high error revealed by rudimentary greenness measure (right top)
  • Many different CO₂ measurements for a greenness value makes prediction more difficult
  • The squared error is parabolic-shaped because one value is assigned to each “band” (right bottom).

Biological reason:

• Same approximate color for different stages of drying
• Moss drying stage dictates CO₂ uptake