TEOS 05 Ecological Studies Using Digital Cameras

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Overview
Shifts in the timing of spring and fall have implications for many ecological processes and relationships, including productivity, species interactions, and community structure. Linking phenology observations with meteorological data and ground processes is important to understanding how these relationships will change. Previously, we have used digital cameras to detect fine-scale timing of phenological events at local and continental scales.

Work on using digital cameras as environmental sensors at CENS has branched into three avenues of investigation: (1) collaboration with researchers in Chile at a Long Term Ecological Research (LTER) station who have digital image archives, (2) collaboration with researchers in Berkeley who maintain a series of webcams, and (3) work with high dynamic range imaging (HDR) that will be obtained from both the James Reserve and the La Selva Biological Station, Costa Rica.

Approach

Collaboration with Chilean LTER
The Chilean team has image data sets obtained on a seasonal basis to estimate total plot plant cover (plant, soil, rocks, litter, etc.) in different watering treatments (Figure 1). We are helping them analyze the image to remove shadows and classify the coverage.

Collaboration with Berkeley researchers
We are involved in evaluating the ability of digital cameras to provide fine-scale phenology observation of target species in two heterogeneous environments where coarse resolution remote sensing observation fails. Separation of species-specific phenology signals and estimation of spring and fall events will be facilitated through the use of simple color processing techniques and modeling.

HDR
We continue to collect daily images from the James Reserve and are analyzing the seasonal color shifts in relation to the micrometeorological data, however focus is now on the techniques of image separation and HDR. Additionally, we are working with the 6 Pan-Tilt-Zoom cameras at the La Selva Biological station in Costa Rica established on the MRI towers project.

System(s) Description and/or Experiments

Collaboration with Chilean LTER
The RGB color space, although native to many image capture systems, does not separate chromaticity or color, from the luminance (lightness and darkness) component of color. Unfortunately, the color variation within an image taken under natural, uncontrolled lighting conditions is principally dominated by variations in luminance, making reliable classification using the RGB color space difficult. A variety of transformations can be used to reduce the effect of luminance in natural light images.

We transformed the RGB data and the region-of-interest (ROI)-based data into different color spaces to test their effectiveness in the models for plant cover prediction. Three-dimensional color spaces included: Normalized RGB, Hue-Saturation-Luminance, Yxy, Lab, ATD, and NDI. Each component of each color space was tested individually as well as in the chromaticity pairs, excluding the luminance component when present. If there was no specific luminance component, then pairs of color components were tested together.

The RGB and alternative color space components were fit to the plant cover data using a recursive partitioning tree to create a set of predictive "rules" for determining what combinations of the values of the color channels were optimal.
for separating plant cover from background soil. We used R and the rpart module to create a binary decision tree using an initial complexity parameter (as a proxy for the number of binary splits, indicating further divisions have less benefit relative to the increased complexity of the tree) of 0.001. An alternative method was also employed for determining plant cover by manually select regions of interest (ROI) within images that represent plants and other ROIs that represent background or soil and calculate the frequency of color values within each group. A simple Bayesian approach (naïve Bayes classifier) was then be used to predict when a combination of color components in similar images was most likely plant or most likely soil. The frequencies of all combinations of RGB and the alternative color space components in the original images were then established for both groups of ROI using a program written in Python. The probability than any color component combination was to be defined as plant cover was defined as the frequency of that combination occurring in the plant cover ROI relative to the frequency of that combination occurring in all ROIs, both plant and soil. A threshold of 0.5 was established for later classifying a color component combination as either plant cover or background.

Collaboration with Berkeley researchers

We use three different color spaces (excess RGB, Lab, HSL) to detect seasonal changes in vegetation of a focal oak species at each study site (Q. kelloggii at James Reserve and Q. douglasii at Tonzi Ranch). Regions of interest (ROIs) containing the focal species will be manually drawn. Vegetation signals will be identified by first averaging per pixel values of each colorspace component (e.g., ExG, L) across image ROIs to create a phenology time series. We then model the timing of spring green-up and fall senescence with a sigmoid function following methodologies used in previous digital camera- and satellite-based phenology studies. The sigmoid approach is relatively robust to signal noise, and phenology metrics (e.g. start of spring) can be estimated from model parameters. We then compare camera detection with that from remote sensing Moderate Resolution Imaging Spectroradiometer (MODIS) products used for large-scale environmental monitoring. MODIS daily surface reflectance at 250 m spatial resolution (MOD09GQ) will be used to for per pixel measurements of vegetation, calculated as the Normalized Difference Vegetation Index (NDVI; \[\text{near infrared reflectance} - \text{red reflectance}\]/\[\text{near infrared reflectance} + \text{red reflectance}\]). Dates of spring and fall will be estimated from modeled times series inflection points.

HDR

Due to the limited dynamic range of image sensors, HDR techniques have been developed to consolidate images that have been varyingly exposed into one image that can fully describe the dynamic range of the scene. While this method is traditionally used to improve the visual quality of a scene, we are more interested in its merit in representing the amount of light reflected by components in a scene. By calibrating HDR images with PAR sensor data, we are able to convert the relative reflectance into an absolute value, allowing us to not only represent the full dynamic range of the scene, but also determine the absolute amount of solar radiation reflected at each spot in the image. This information can be used to more accurately measure the amount of energy absorbed by the flora in observed scenes. We are currently testing this approach with datasets collected from the James Reserve and the La Selva Biological Station in Costa Rica.

Accomplishments

Collaboration with Chilean LTER

The optimal RGB binary decision tree created with rpart using the SamplePoint RGB components to predict plant cover consisted of 32 splits with a relative cross validation error of 0.54 (Fig. 1A). The RGB decision tree was able to correctly predict 83.21% of the SamplePoint plant cover classification. The two color components that ranked the highest in correctly identifying plant cover were HSL nad Yxy (Figure 2.)

Collaboration with Berkeley researchers

Cameras are able to detect Q. kelloggii phenological signal at James Reserve, where there is no discernable phenological signal from satellite imagery. Different colorspace show varying success in detecting Q. kelloggii spring and fall events. In particular, ExR and b from Lab show strong peaks that correspond with the timing of fall coloring events. ExG and a from Lab show sharp increases that correspond to spring green-up. Tonzi Ranch, in contrast, shows strong seasonal signals in satellite measured NDVI. The phenological signals of Q. douglasii and annual grasses, however, cannot be distinguished from satellite. Cameras are expected to provide species-specific phenological signals for the ecosystem. Challenges with camera-based detection stemmed from variation in color caused by automatic color balance camera settings and changes in luminance.
Future Directions
Continued work with color separation of the Chilean plots and the Berkeley locations will allow us to analyze seasonal trends and eventually annual productivity.

HDR promises to allow us to retrieve absolute values of reflectance from vegetation and thus facilitate a back-calculation of what solar input photosynthetic tissues are receiving. A final carbon budget for the field of view of the camera on an hourly, daily, and seasonal basis will then be possible.