TEOS 05 Use of High Dynamic Range Imaging in Ecological Studies

TEOS 05.1 People

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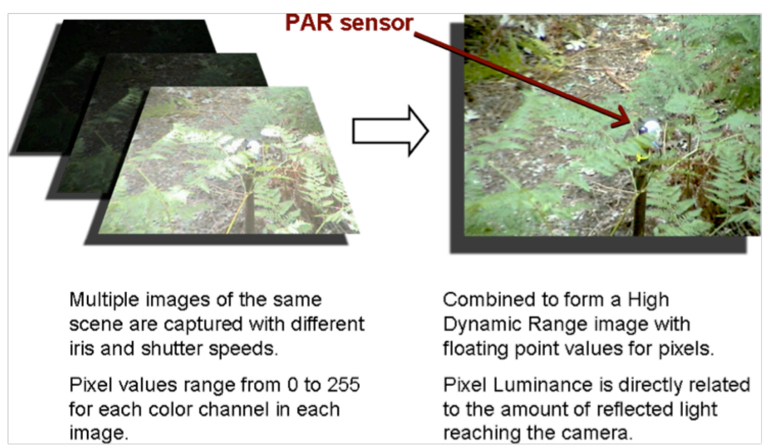
TEOS 05.2 Overview

The use of tiered systems of sensing, comprised of high-resolution, high accuracy “spot” sensors placed in the environment coupled with a lower resolution but wider “field of view” sensor, such as a camera, has been proposed as an efficient method of measuring heterogeneous environments. We have designed such a system and deployed it at the James Reserve, where multiple photosynthetically active radiation (PAR) sensors were deployed in the understory near a bracken fern colony alongside a pan-tilt-zoom (PTZ) camera that recorded fern frond reflectance using high dynamic range (HDR) imaging. We have now made a correlation between the reflectance from the ferns and the PAR they received, allowing us to model fern frond photosynthesis over the entire understory colony.

TEOS 05.3 Approach

Measuring light in a heterogeneous understory, specifically sunflecks, is difficult because of the transient nature of the patches of light and the spatially complex patterns they create. Capturing the spatial distribution of sunflecks would require many fixed PAR sensors or a fewer number of mobile PAR sensors. Alternatively, a camera with a wide view of the environment, if calibrated with fixed PAR sensors for the reflectance of a uniform surface, can be used with each pixel acting as a PAR sensor. One issue with using cameras as sensors is that automatic gain, shutter speed, aperture, and white balance (all designed to make visually appealing images) remove the necessary data that can be used for calibration purposes. Overriding the automatic setting and creating HDR images by combining multiple images of the same scene captured with different shutter speed and aperture combinations allows us to calibrate the resulting image to the actual light intensity received by the camera. A calibration of received light intensity to that measured *in situ* will allow us to correlate pixel values to PAR values.



HDR images are created in a number of steps. To capture a regular image, a digital camera employs a number of red, green, and blue sensors behind a lens. The camera reads the amount of light hitting each sensor, and translates these values into an image. Each image contains a number of pixels and each pixel contains a red, a green, and a blue byte value that ranges from 0 to 255. We assume the existence of a non-linear transformation from the light read at the sensors to the final byte values of the image. The first step to create an HDR image is to capture a number of images at various exposures, and use the images to recreate this transformation curve. The inverse of the transformation will take a byte value from 0 to 255 and return the actual value read at the sensor. An example of this transformation can be seen in figure 2.

To create the actual HDR image we again take a number of images of a scene using various exposure settings. For every pixel location, we look at every image and translate the byte value back into a sensor value multiplied by the exposure settings. Since we know that the camera sensors are most accurate when returning values from the middle of their range (e.g., 127), we weight values near 127 more than values near 0 or 255 (the edge of the sensor range). In theory, for every pixel location we will find at least one image with exposure settings that give around a 127 byte value. In the end, the HDR image is a weighted average of the byte values translated back into sensor values using the calibrated transformation from above.

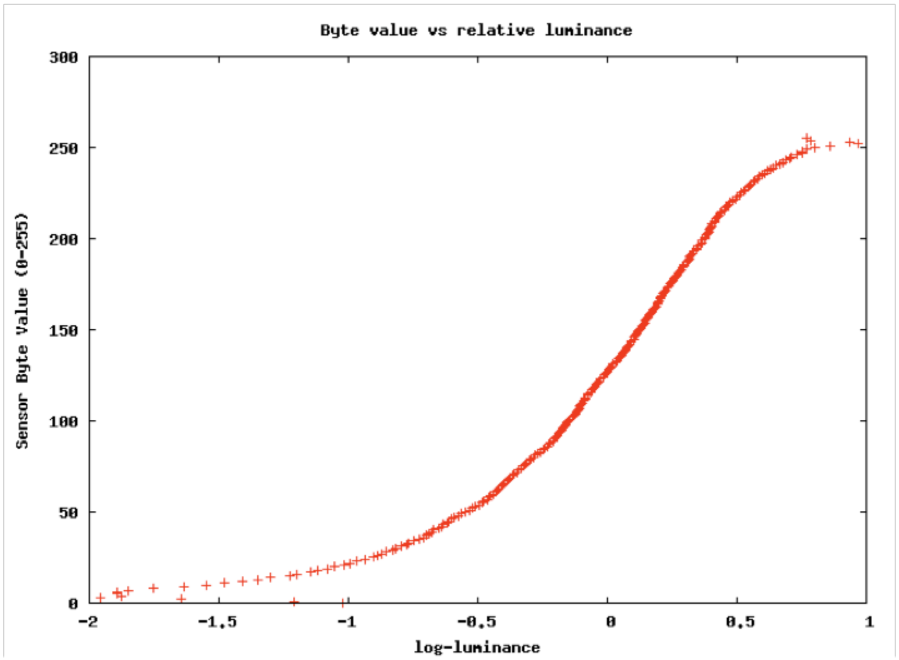


Fig. 2: Response curve of a camera. Notice the curve is linear near 127, but very non-linear near the extremes.

The advantages of HDR images are many. They allow us to capture meaningful images in almost any lighting condition, even when half the image is in direct sunlight and half the image is in dark shade (a condition that would cause a normal image to lose information). Since we have more detail, many automatic image processing algorithms work better. Also, the HDR image algorithm conveniently provides us with a relative luminance value at each pixel. In theory, this should directly relate to the actual amount of sunlight reflecting off an object. The main disadvantage of HDR images stems from the fact it can take up to 30 seconds to take the required images. This allows within image movement, such as plants waving in the wind, to cause blurring and other artifacts.

TEOS 05.4 System(s) Description and/or Experiments

Six Licor PAR sensors were deployed at approximately 1 m height in different locations around an area of bracken ferns at the James Reserve. The sensors were attached to a Campbell Scientific datalogger which collected PAR data at 2 s intervals from all sensors and relayed the data via Bluetooth to the NIMS 1 PC/104. The NIMS 1 also carried a Sony PTZ camera, which was tasked with constantly capturing images over the course of a day of areas of bracken ferns that included PAR sensors. Each capture was composed of a sequence of images that included multiple shutter speed and aperture combinations.

To properly combine the images into a single HDR image, each pixel at a specific position in an image must match the same pixel in each of the other images. However, the wind tends to cause the camera to sway as well as the ferns themselves. Camera movement causes the image to be shifted slightly and can be corrected using freely available open source image alignment tools. Hugin tools, a package originally designed to stitch together images to create panoramic views, works well for this. We have created a set of scripts that use these tools to automatically align the images and to drop any images that are too far off to be accurately aligned. Dealing with the ferns themselves moving in the wind is theoretically possible using the latest image techniques, but we have not felt it worthwhile to explore that route. We simply drop images that have too much within image movement.

Once the images are aligned, we use another set of open source tools to transform them into a single HDR image. Again, we have created scripts to automate this process. The scripts reads in the aligned images, creates the HDR image, and for every HDR image creates a log file containing details such as the time range in which the HDR image was taken. Once the HDR image is created, we can find a relative luminance value for every pixel.

To create a calibration of HDR luminance to PAR, masks of fern surfaces near the PAR sensor were manually created and applied to a subset of images. Then average pixel luminance values indicated by the masks are regressed against PAR values taken concurrently. An example of calibration data is in Fig. 2.

TEOS 05.5 Accomplishments

Calibration indicates that a linear relationship exists between luminance values in the HDR images and PAR.

TEOS 05.6 Future Directions

Next steps include applying the calibration to the HDR images captured through the day and then comparing the PAR distributions to the locations of bracken ferns. Photosynthetic light response curves have already been established and the calibrated pixels will be fed into this physiological model, assuming no other limitations to photosynthesis, and net carbon for a day will be estimated. Percentage of net photosynthesis under direct versus sunfleck conditions and minimum light requirements will be calculated.