Radiometric Calibration of a Modified DSLR for NDVI

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ABSTRACT

Silicon CCD detectors found in commercial DSLR cameras are responsive far out into the Near Infrared wavelengths. These cameras typically have an Infrared block filter built in to more closely resemble the human visual system. This paper proposes a method for radiometric calibration in order to extract NIR and RED Radiance bands from a Canon 300D with the IR filter removed. With these spectral bands a single exposure NDVI measurement can be produced for each pixel in an image for identification of live green vegetation.

Keywords: NDVI, Low Pass Filter, DSLR, Multispectral

1. INTRODUCTION

In recent years, there has been an increase in demand for low cost, light weight, multi-spectral cameras. The demand for these systems has come primarily from the agricultural industry. Precision agriculture is the optimization of farm management with the goal of increasing returns. For many years, a big part of precision agriculture has been the application of infrared imagery in order to monitor crop growth and health. In particular the Normalized Difference Vegetation Index (NDVI) has provided a way to measure the relative amount of chlorophyll in a plant. Typically NDVI has been measured via spaceborne imagers that have high demand for use as well as large ground pixel size (typically ¿1 meter) which makes them less than optimal for precision agriculture. However, the increase of cheap, commercially available Unmanned Aerial Vehicles (UAVs) has driven the demand for small NDVI capable systems. The idea being that a small camera mounted on UAV could provide high resolution imagery for growers to optimize their operations.[1]

One of the main goals of environmental remote sensing is identification and classification of different materials through multi-spectral and hyper-spectral imagery. Specifically, the detecting of vegetation has dominated many areas of research as well as commercial applications for remote sensing. In the early 1970s, NASA launched an earth monitoring satellite called Earth Resources Technology Satellite 1 (ERTS-1 later called Landsat 1). ERTS-1 imaged different parts of the earth in both the IR and visible wavelengths. The researches at NASA working on this projected conducted studies of seasonal health of vegetation and the response of in the IR imagery. The results of the studies showed that vegetation heath could be correlated with the amount of IR being reflected by the plant. The mechanism behind this correlation lies in the photosensitive pigments called chlorophyll found in most vegetation. Chlorophyll absorb light energy and begin the process of photosynthesis which is the plant's way of creating energy. The light that is absorbed at certain wavelengths mostly in the visible region in the red and blue wavelengths. Chlorophyll also reflect and scatter a great deal of IR light. The amount of IR light is proportional to the amount of chlorophyll in the plant and therefore a good metric of how much energy the plant is producing.[2]

The amount of energy the plant is producing is a good indicator of the health of the plant. Figure 1 shows the radiance emitted from vegetation as a function of wavelength. The first plot shows a healthy plant (more chlorophyll) and the second shows a plant that is unhealthy. The NASA scientists working on these studies developed a method for quantizing this IR response in which it was corrected for the different sun angles in their imagery. The result was the normalized difference between the response in the IR and the response in the visible wavelengths or NDVI.

In modern systems NDVI is computed using a red and an IR reflectance or radiance band as shown in Equation 1.

$$NDVI = \frac{IR - RED}{IR + RED} \tag{1}$$

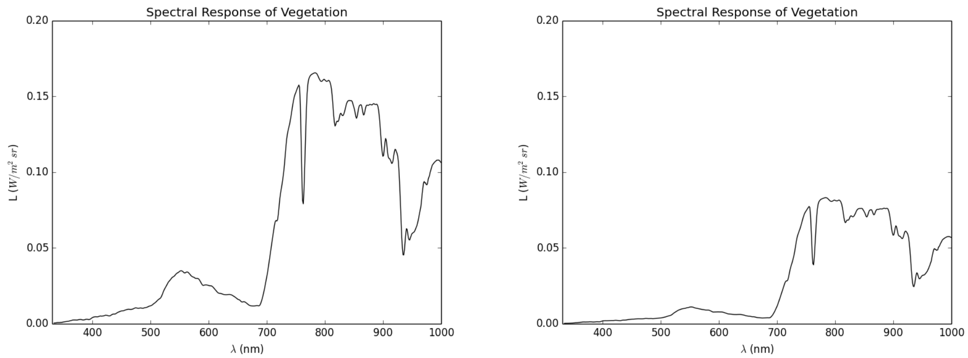

Figure 1. Spectral signature of healthy (left) and unhealthy (right)

NDVI is used often in environmental remote sensing to study vegetation phenology, deforestation, and biomass. These applications used mostly airborne and spaceborne sensors that typically have pixel resolution greater than 1 meter[2]. Orbital systems provide large sample areas and used primarily in research. The large scale and costs of these systems make them generally impractical for commercial use in the private sector. However, in recent years there has been an increased demand for NDVI capable systems in the Agricultural Industry.

Precision Agriculture is the optimization of growing crops in order to efficiently produce greater returns. One way this is done is through use of NDVI imagery to more efficiently deal with areas of diseased or stressed crops. If a grower knows where the crops are stressed, they can deal more directly with the issue whether it be inadequate watering or fertilizing. The orbital systems that typically provide NDVI imagery are not ideal for this application. There is demand for a smaller, cheaper way to provide this imagery to growers in real time so that they can take advantage of the information it provides.

The demand for new NDVI capable systems has also increased with the recent increase in cheap commercially available unmanned aerial vehicles (UAVs). UAVs whether they are fixed wing or multi-rotor systems provide a new mechanism for collecting this imagery for a lower cost than previously possible. While a UAV provides a mechanism for data collection, it adds constraints to the desired imaging system. For applications in precision agriculture, the system must be able to capture IR and red radiance bands, be light weight (for UAV use), be able to provide sub meter resolution, and be relatively inexpensive.

There have been several different methods for designing a system that meets the demands for the Precision Agriculture industry. One method involves a multi sensor system that recovers one band per CCD sensor by use of spectral filters. The sensors are mounted some fixed distance apart from one another and registered together. This allows for multiple bands to be collected at the same time. While this method works for recovering NDVI imagery, the multiple sensors can make the system more expensive.

This paper implements a alternative to this first method outlined by Rabatel, et al. In this method, an IR and red radiance band is recovered from a modified consumer DLSR camera. The IR filter in the camera was removed and a low pass filter was introduced on the front of the camera. The low pass filter works by blocking light below 600 nm effectively turning the cameras 'blue' channel into an IR channel. The IR response can the be subtracted from the red channel and NDVI can be computed.[3]

2. METHOD

2.1 Camera Modification

A typical consumer digital camera has either a CCD or CMOS sensor. These sensors are made with silicon which is typically responsive to light over a spectral range from 300 to 1100 nm. In order to create images that more closely resemble the human visual system, this range is reduced to about 300 to 700 nm. Camera manufacturers do this by placing a IR blocking filter in front of the sensor. The camera we will be using is a Canon 300D DSLR which had a range from 350 to 700 nm with the IR filter as seen in figure 2.[4] After the filter was removed

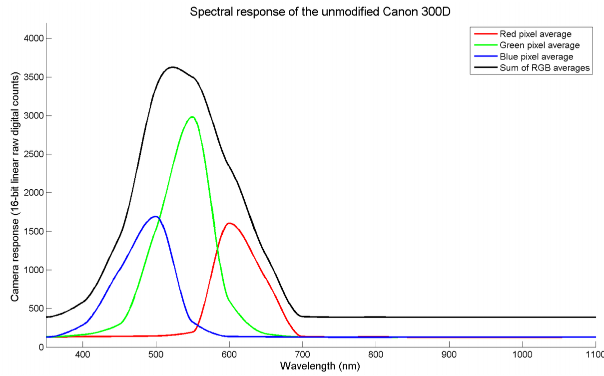

Figure 2. Response of camera bands before modification

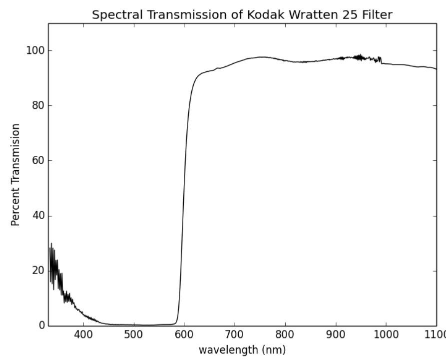

Figure 3. Transmission of low pass filter

the response drastically change. The difference between these responses is the IR response being introduced. Normally the camera forms it's three channels through the Color Filter Array (CFA) on top of the sensor. The CFA is made up of either red, green, or blue filters and these primaries are how the camera recreates colors in the output image (for clarity these channels with be referred to as band 1, band 2, and band 3 respectively). With the modified camera the IR light is not filtered by the CFA and therefore makes a contribution in each of the cameras three bands. However, this added response is not easily extracted from the output of the camera. These spectral band passes are integrated over by the camera's sensor and the IR bandpass needs to be separated. This is achieved using a low pass filter.

2.2 Low Pass Filter

The low pass filter is essentially a "blue" block filter. It optimally blocks light below a wavelength of 600 nm. In band 3 of our camera we can see this reduces the band pass to only the IR wavelengths. As outlined in Rabatel, et al, one suggested filter is a Kodak Wratten No. 25 red filter. The transmission of this filter was measured and can be seen in Figure 3 The response functions of each camera band can be seen in figure before and after application of the Wratten filter in Figure 4.

In order to extract a red band, the IR response needs to be subtracted away from band 1. To perform this subtraction, the IR component in band 3 and band 1 must be the same. This is not the case with consumer digital cameras. Each band is represented in camera digital counts and are explicitly proportional across each band. We must ensure the IR response we are subtracting out is the same in both bands. This is done through radiometric calibration. The digital counts in each band need to be associated with real world values.

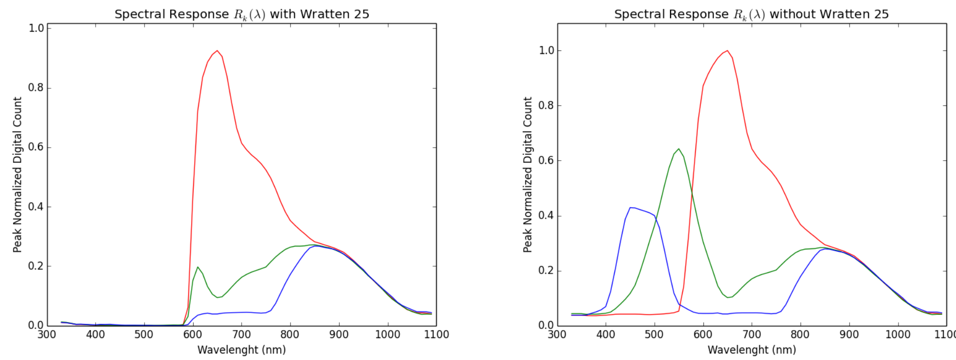

Figure 4. Response functions of camera bands with(left) and without(right) low pass filter

2.3 Radiometric Calibration

The calibration process requires that the relationship between digital counts (DCs) and sensor reaching radiance (L) be modeled. If we assume this relationship is linear, we can represent it as shown in Equation 2

$$DC_{k,i} = \alpha_k L_{k,i} + \beta_k \qquad k = \text{bands } 1,2,3 \ i = 0 \text{ to saturating total radiance} \tag{2}$$

Where α is the linear coefficient and β is the offset for each of the k camera bands. This relationship was measured with a integrating sphere and a calibrated light source. An image was captured of the sphere at several different output levels of the source (i). The spectral output of the source (L_s) was also captured at each of the i levels as well with a spectrometer (SVC spectraVista). This however, was not sufficient to convert to radiance bands because L_k is not equivalent to L_s. The calibration needs to account for spectral variations in the source as well as each of the different CFA filters. Equation 3 shows how we account for the spectral variations in our model.

$$L_{k,i} = \sum_{\lambda=330}^{1100} R_k(\lambda) \cdot L_{s,i}(\lambda) \tag{3}$$

The effective response for each camera channel (R_k) was measured with a monochromator and an integrating sphere. The wavelengths from 330 to 1100 nm were stepped through in 10 nm steps and an image was captured of the sphere at each step. A mean DC was extracted from each image and the values were adjusted for the source power output and then peak normalized to the highest camera response which occurred in band 1. The resulting response functions can be seen in Figure 4. We then insert our new spectrally adjusted sensor reaching radiance into Equation 2 to get our new model as seen in Equation 4.

$$DC_{k,i} = \alpha_k \sum_{\lambda=330}^{1100} R_k(\lambda) \cdot L_{s,i}(\lambda) + \beta_k \tag{4}$$

Thus far, this method calibrates for our system without the low pass filter. It should be noted that if the goal were to recover radiance bands for the camera sensors as is, this is all the calibration that would be needed. For our purposes, we need to introduce the low pass filter's contribution to sensor reaching radiance (L). The transmission of the filter as a function of wavelength (T_{w25}) was measured with a spectrometer and is seen in Figure 3. This transmission is introduced into our model as seen in Equation 5.

$$DC_{k,i} = \alpha_k \sum_{\lambda=330}^{1100} R_k(\lambda) \cdot L_{s,i}(\lambda) \cdot T_{w25}(\lambda) + \beta_k \tag{5}$$

The coefficients (α_k) and offsets (β_k) can be recovered via linear regression of this relationship.

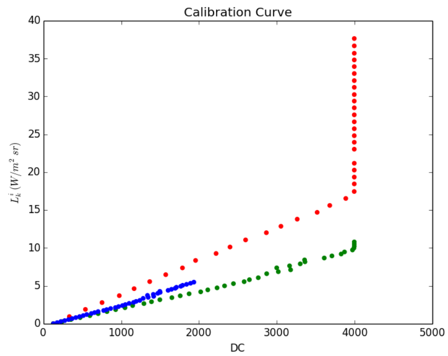

Figure 5. Relationship between digital count and sensor reaching radiance without filter.

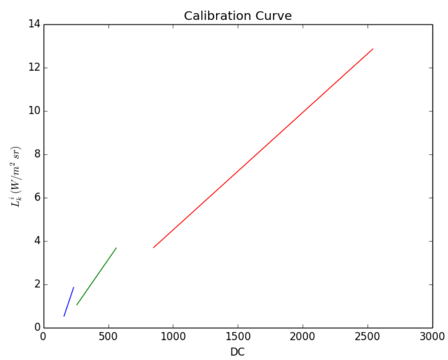

Figure 6. Relationship between digital count and sensor reaching radiance with Wratten Filter.

2.4 Application of Calibration

Once the calibration coefficients are recovered for each camera band, they can be applied to a new image taken with the camera. A raw image is captured and demosaicked without any spatial interpolation in order to preserve the original sensor digital counts. This process reduces the image resolution to 1/4 the sensor size. Each band is entirely multiplied by its corresponding calibration coefficient. The offsets are added in the same fashion. The values at each pixel is now in radiance units ($W/m^2 sr$).

2.5 NDVI Calculation

Once the radiance bands are created from the calibration, the NDVI image can be computed. The IR response in band 1 is proportional the IR response in band 3. To recover the red band we subtract band 3 from band 1. With this new red band and band 3 as our IR band we can compute the NDVI. Equation 6 denotes this calculation in terms of our radiance bands where band 1 is $B1$ and band 3 is $B3$.

$$NDVI = \frac{2 * B3 - B1}{B1} \tag{6}$$

3. RESULTS

The Calibration process was preformed as prescirbe ith the previous sections and the results can be seen in Figure 5 and Figure 6. Figure 5 shows the relationship between sensor reaching radiance and DCs without the Wratten Filter. Figure 6 shows the same relationship with the filter.

Several images were captured over a month and a half period in late September and October in Rochester, NY. These images show vegetation on the campus at Rochester Institute of Technology as the plants go into senescence with the onset of fall. Images were captured only when vegetation was in direct sunlight and close to solar noon. These images can be seen in Figure 7

4. CONCLUSION

We can draw many conclusions from the images resulting from this calibration method. The images in Figure **??** show that the NDVI values for the vegetation decrease with the onset of fall in 2014. This is as expected. The plants begin to lose their foliage as they go dormant for the winter. THe majority of the trees in the image progressively become darker which corresponds to a lower NDVI value. Another thing we notice in these images is that the pine trees and other evergreen trees remain relatively the same throughout all of these images. This is serves to validate our model because the evergreen trees do not go dormant and lose biomass like other plants. It should be noted that the values qualitatively trend as we would expect and this does not confirm explicitly that the radiance values in our calibrated images are correct. The most that can be said is that proportionally, the red and IR bands are correct on a qualitative level.

Future work could include testing the radiance values in the lab with a controlled light source and a spectrometer like the SVC. The radiance could be measured off of a standard with both the camera and the spectrometer to check the radiance bands

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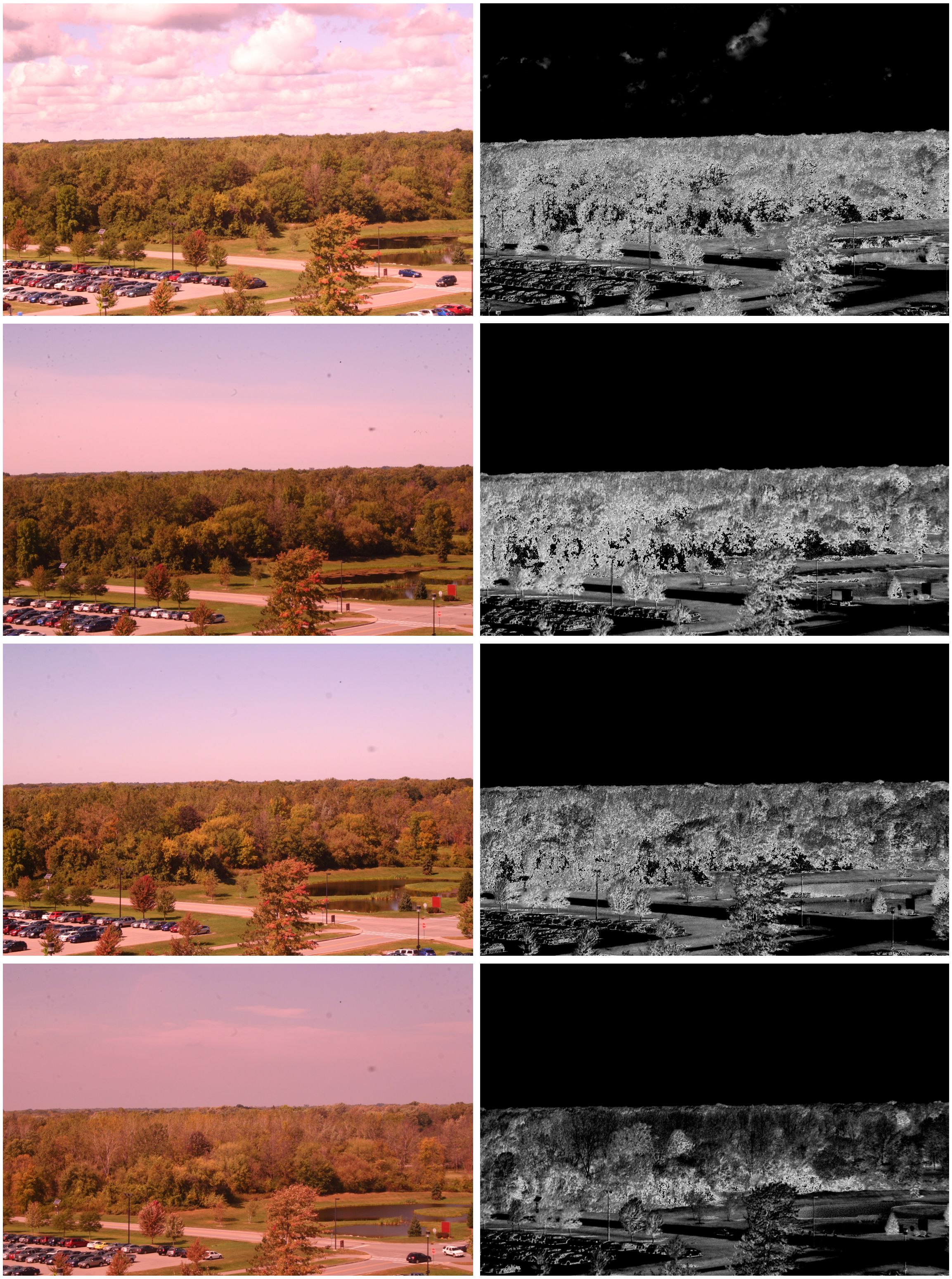

Figure 7. Normal color image (left) and NDVI image (right) over five week period in Rochester, NY.