

Modeling the Spectral Effects of Water and Soil as Surface Contaminants in a High Resolution Optical Image Simulation

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Abstract—The primary interest of this research is to introduce selected environmental effects into RIT’s Digital Imaging and Remote Sensing Image Generation (DIRSIG) Model. DIRSIG is capable of producing high resolution images (meter scale) using Computer Aided Design models (CAD) of buildings, vehicles, trees, etc. across the full optical spectrum (0.35-25 μ m). Currently, these objects are modeled in a pristine manner and there is no option to simulate them after exposure to environmental effects.

Ideally, we would like to subject a given material to these environmental effects and then accurately model the modified reflected or emitted spectrum. As a first step, we have chosen to model moisture and dust on surfaces by implementing a model of the effects of a thin layer of water and soil coverage, respectively, on the spectral reflectance and emittance of different materials.

Using new techniques for field instruments in a laboratory setting, we have established the relationship between the surface contaminant and its effect on the target in question. These results will be incorporated into the DIRSIG modeling tool for wider use.

I. INTRODUCTION

The primary interest of this research is to introduce environmental effects into the Digital Imaging and Remote Sensing Image Generation (DIRSIG) Model. Ideally, we would like to be able to choose a material, change its surface conditions and retrieve the reflected or emitted spectrum. There are several approaches that may be taken to this problem and many different environmental effects that could be considered. In order to limit the scope of this research, we have chosen a couple of areas to focus on that fall under the larger umbrella of environmental effects.

Let’s begin by discussing what the large umbrella covers. Figure 1 provides the taxonomy of some environmental effects. There are two main categories: target and background. The target is of primary interest in a scene and in most remote sensing work, but the background must also be well understood. One of the reasons is that the background may have an influence on the target of interest. We are interested in the effects that certain contaminants that are part of the background, such as water or dust, may have on the spectra of the target. Examples of this would be transmissive or non-uniform layers of dust on a vehicle’s surface and puddles of water on a road.

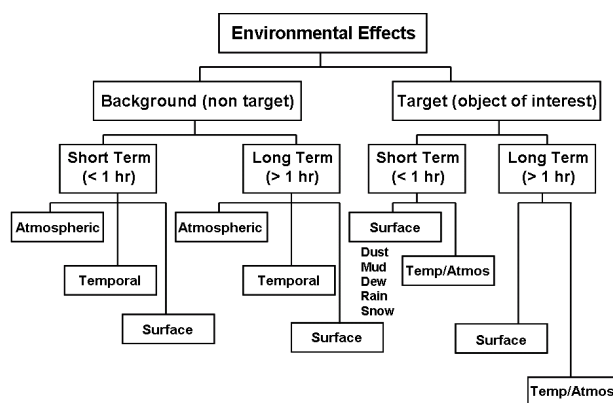


Fig. 1. Environmental Effects Taxonomy

These two areas are then further divided into sub-categories that are defined by their duration. Short-term effects are those which are transient in nature, such as weather. These effects would show up as changes in successive observations. Long-term effects, on the other hand, have a longer duration and would not show up as changes in repeated observations over a short timescale. These categories are also sub-divided into atmospheric, surface and temporal effects. We are interested in the short term surface effects on a target. The surface effects that we will investigate are soil and water on a variety of manmade surfaces.

II. EXPERIMENTAL DATA COLLECTION

As a first step in this model implementation, the spectral effects of these contaminants were measured in field as well as laboratory settings. Four surfaces were used in our measurements: asphalt, concrete, roofing material and painted metal. In the first scenario, a commercial grade sand was used to cover these surfaces. There are several factors which may influence the spectra of a surface contaminated with a soil: particle size distribution, layer thickness and areal coverage. We have chosen to limit our analysis to the areal coverage of optically thick piles of sand on each of the target materials.

In making the piles optically thick we are able to eliminate the effect of the layer thickness on the spectra. We have also only removed the largest particles in the sand mixture, thereby covering a wide variety of grain sizes in our measurements.

Water as a contaminant is more challenging to investigate experimentally. Since very little water on a surface will cause the layer to act as a blackbody, the amount of water added to the surface will need to be assessed very carefully. As an added level of difficulty, most instruments that are available in our laboratory utilize a heat source to obtain measurements in the longwave portion of the spectrum. While collecting data on dry samples will not be a problem, wet or moist samples, however, will tend to dry during the measurement time. Wet surfaces are thus being analyzed as water is incrementally added to the surface. Evaporation between measurements will need to be considered as well.

III. INSTRUMENT SET-UP DESCRIPTION

When spectral measurements are made it is important to be able to look at a full spectrum measurement to get the full picture. Our research is interested in the full spectrum, 0.35-25 μm . This task is ambitious and not without difficulties. For the purpose of simplicity, the spectrum of interest will be divided into two categories: 0.35-2.5 μm and 2-25 μm . The former is what is commonly referred to as the reflective region and encompasses the Visible, Near-Infrared and Short-Wave Infrared (VNIR/SWIR) regions. The latter contains the Mid-Wave Infrared (MWIR) and Long-Wave Infrared (LWIR) regions and is typically referred to as the emissive portion of the spectrum.

Measurements over each of these regions can be done with two instruments, respectively. The reflective region was measured with the Analytical Spectral Devices (ASD) Field-Spec Pro Spectroradiometer. The ASD is a field spectrometer that measures the reflectance spectra of surfaces in the VNIR/SWIR region of the spectrum (0.35-2.5 μm). The emissive region was measured with a portable FTIR spectrometer from D&P Instruments. The D&P complements the ASD by providing emissivity measurements from 2 to 25 μm .

A. Field & Laboratory Set-up

Both of these instruments are intended for use in the field. They are lightweight, compact and perform well outdoors. Our first set of measurements was made in the field and followed the protocols for each of the instruments. The field measurements were primarily of vehicles. The set-up was modified such that measurements using both instruments could be made simultaneously. An elevated platform was used to make measurements of the hoods and roofs of a variety of vehicles.

In order to move into the laboratory setting, however, a new procedure and set-up for each of the instruments was created. Both of these instruments could not be used in the same environment within the laboratory due to sensitivities to different factors contributing to the spectra in the different regions.

We placed the ASD in a darkened room to reduce the amount of contributing light from sources other than the target itself. The amount of stray light needs to be minimized or kept constant when making any measurements in the reflective region. The ASD has three detectors, each responsible for the visible, near-infrared and short-wave infrared regions of the spectrum, respectively. An interesting feature of the ASD is that the optic fibres associated with each of the detectors are not randomly distributed nor do their fields of view overlap. This can result in large discontinuities between each of the spectral regions. This is especially true when the measured surface has spatial regions that are very different in texture and spectral variation. In our case, placing sand on any of the surfaces easily created these different regions and, therefore, large discontinuities. In order to overcome this limitation, samples were placed on a rotating platform. Several measurements of each sample were taken over one revolution and then averaged. This removed or reduced any discontinuities from the measured spectra.

As previously mentioned, the D&P requires a different set-up for proper measurements to be taken. The simplest way to look at the requirements of the D&P is the fundamental equation governing the processing of its data:

$$\epsilon(\lambda) = \frac{L_S - L_{DWR}}{L_{BB} - L_{DWR}} \quad (1)$$

where L_S is the radiance of the sample, L_{DWR} is the measured downwelled radiance and L_{BB} is the radiance of a blackbody at the sample temperature. In the field, the necessary contrast occurs naturally because the cold sky contributes the downwelled portion. Since our laboratory was indoors and, as such, did not have a sky, we needed to 'invent' one. This was done by creating a level of iced-filled pans, under which we could place the samples to be measured.

Another important consideration for the D&P that is not necessary for the ASD measurements is temperature control. Since the emissive portion of the spectrum is temperature dependent, the samples were heated prior to and during the course of making the measurements. Data processing also required knowledge of the temperature at each measurement.

IV. DATA COLLECTED

Once the testing of these set-ups was complete, measurements could be made. In the field, we were primarily interested in measuring vehicles in a variety of different states: dry, wet, clean and dirty. These four states were combined to create four different surface conditions: dry and dirty, dry and clean, wet and dirty and wet and clean. Asphalt was also measured in all four states. These measurements were made to get a qualitative idea of how the surface characteristics changed as a function of the contaminant and also over the different wavelength regions. All of these measurements were made with both the ASD and the D&P.

The laboratory measurements were also made by both instruments, with sand and water as surface contaminants. What differed at this stage was the quantitative aspect of the

measurements. More effort was made to control how much soil or water was on the surface and the temperature of the samples was also carefully noted. As well, in the laboratory we investigated the surface contaminant effects on the four different surfaces: asphalt, concrete, painted metal and roofing material.

Using the field and laboratory data collected as described above, an analysis will be done to determine the relationship between the reflectance/emissivity and the areal coverage. Based on the outcome, mixture models, linear or non-linear as the case may be, can be used to model the results for use in DIRSIG.

In order to determine the relationship, optically thick piles were placed on the surface within the field of view of the instrument. Beginning with a bare surface, the number of piles was increased to the point of complete coverage.



Fig. 2. Soil Coverage

Water as a surface contaminant was addressed in much the same manner. Only two surfaces, the asphalt and concrete, were used in these measurements. A bare surface would have increasing amounts of water put on it until complete saturation was achieved. The quantitative assessment of how much water was on the surface was not as precise as that for sand. Instead, an approximation of the amount of water on the surface was made.

V. EMPIRICAL DATA ANALYSIS

The following results are samples of the data set that was acquired over the course of this research. The plots in Figure 3 indicate the differences between the four different states of the reflective and LWIR regions for a vehicle. As expected, the emissivity increases towards 1 as the amount of water on the surface is increased (right). The transmissive properties of water may also be seen in the visible portion of the spectrum by the fact that there is very little impact on the spectra when water is added to the surface. These results are qualitative but they do reveal the anticipated trends.

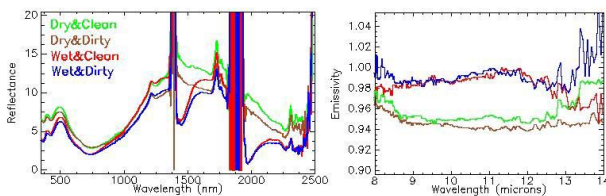


Fig. 3. Subaru Spectra

In the laboratory, several measurements were made of different surfaces, with varying amounts and different contaminants.

One of the more complex surfaces that was measured was a sheet of red painted metal. The following figure shows how increasing the amount of sand on the surface alters the original spectra differently across the wavelength region. In some regions, the original spectral reflectance is decreased to that of the bare contaminant and in others it is increased.

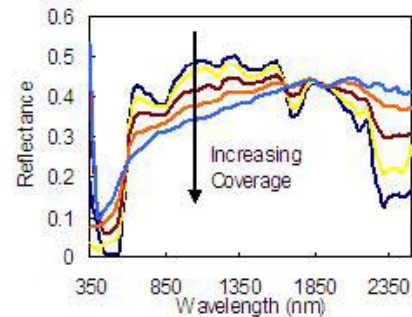


Fig. 4. Painted Metal with Sand

Measurements taken in the LWIR worked very well and show the expected quartz doublets between 8-9 μm and 12-12.5 μm . Figure 5 is an example of the spectra of asphalt with increasing sand coverage in the longwave region.

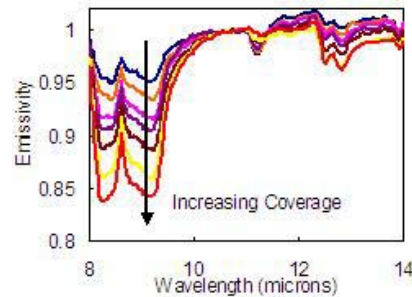


Fig. 5. Asphalt with Sand

Sand is somewhat simpler to quantify on any of these surfaces, because it will remain on top of the material being measured. Water, on the other hand, can penetrate into a surface. This is especially true for porous surfaces like asphalt and concrete. In these instances, it is far more difficult to assess how much water remains on the surface and how much has penetrated beyond the reach of the measuring instrument. The following figure shows how the reflectance of a concrete sample changes with an increasing amount of water on its surface. The visible region shows very little change in reflectance with increasing water content when compared to the SWIR region in which the reflectance goes to zero with saturation.

VI. MODEL-BASED ANALYSIS

Now that the measurements are complete, the next step was to create a model that will allow us to incorporate these results into DIRSIG. Taking a look at the most complex surface,

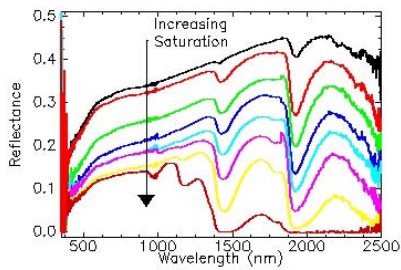


Fig. 6. Concrete with Water

the painted metal, we can see from Figure 7 that the change in reflectance as a function of coverage (with sand) is not linear, nor is it the same across the spectrum. Although this relationship changes as a function of wavelength, the curves that overlay the measured results fit very well.

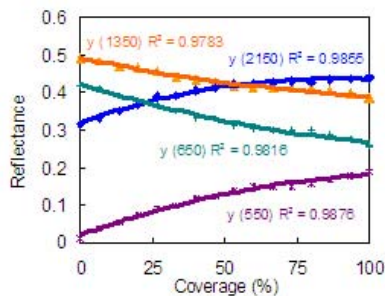


Fig. 7. Spectral Dependence of Reflectance on Soil Coverage

The following two figures give an indication of the type of relationship that can be dealt with by a linear combination of the target and contaminant spectra. In this case, as the coverage of the asphalt increases from 0 to 100 percent, the reflectance changes in a linear manner for any wavelength in this region.

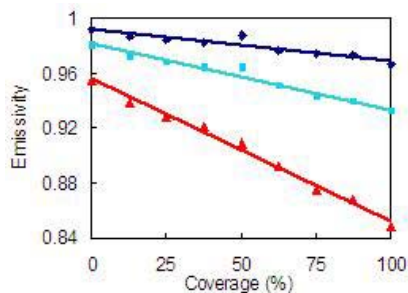


Fig. 8. Linear Relationship

As a result, it is possible to weight the measured spectra of the pure contaminant and bare surface, respectively, so that the sum of the weights equals 1. This allows the user to determine the spectra of any coverage amount for this surface by simply knowing the two spectra. Figure 9 is the painted metal surface with increasing amounts of sand. The solid lines

represent the measured spectra and the dotted lines are the linear combinations for each percentage coverage. There is very little difference between the measured and calculated values.

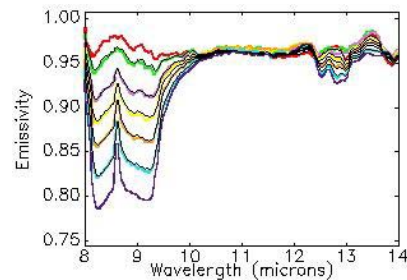


Fig. 9. Linear Combination Comparison

Clearly, this surface represents the easiest case. Other surface and contaminant combinations might create a non-linear relationship between the reflectance and areal coverage. For this reason, both linear and non-linear mixing models need to be investigated. It is possible by using these methods that any surface and contaminant combination could then be modeled. The end result would allow a DIRSIG user to create a scene with any amount of coverage.

VII. CONCLUSION AND FUTURE WORK

This research shows that it is possible to incorporate measured data into a simulation tool such as DIRSIG in order to create scenes that are representative of the real world: dirty and wet. More work should be done in this area to extend the number of contaminants.

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