Texture characterization in DIRSIG

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Abstract

This research project tested the quality of DIRSIG's texture characterization routines for a grass target and potential techniques to improve it. The objective of the DIRSIG is to produce output images that are analogous to real image outputs so the model can be applied to a wide range of problems. It is very important that both spectral and spatial properties of targets are modeled correctly to obtain realistic results.

DIRSIG applies texture to each pixel spectrally. Current techniques examine only one bandpass region, using statistical means to compare a texture image in that bandpass with a spectral database in order to determine which curve will be used for a particular pixel. The research in this project examined the quality of this procedure, and several potential methods for improvement.

DIRSIG images were generated to simulate two different scenes for which real images exist. ENVI's principle components analysis utility was than used to quantify the information in each image for comparison. Modifications were than made to the process to expand the spectral database, and incorporate a new algorithm into DIRSIG that examines multiple bandpass regions when determining which spectra to use for a pixel. The output for each of these new scenarios was than tested for comparison with DIRSIG's previous results, and the results obtained for the truth images.

This research has quantitatively examined the ability of DIRSIG to replicate real world texture characteristics, specifically for a grass target. Research discovered a large gap between the amount of information that is contained in images of real world data and those simulated by DIRSIG. Expanding the spectral database did produce a slight increase in results, increasing the qualitative appearance of the image as well. The amount of data contained in the DIRSIG image remained significantly less than that contained in the real image. Increasing the number of bandpasses employed by DIRSIG in determining which spectra to map onto a particular pixel, results indicated two different concepts.

Adding one band increased the ability of DIRSIG to map correctly choose the spectra. Additional bandpasses may increase the quality of an image, however, choosing too many bandpass regions for an image can cause the resulting quality of the image to decrease. The process is very complex, the output quality is dependent on the particular imaging system that is being modeled, the bandpasses that are chosen, and the amount of bandpasses that are used as references.

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Introduction

Background

DIRSIG is a synthetic image generator used to model sensor outputs in various image acquisition scenarios. AutoCAD\textsuperscript{4} wire frame drawings of objects are used in order to construct a scene. These drawings are used to create synthetic images that represent their truth counterparts. Thermal and reflectance properties for various objects are incorporated into the model as well. Finally, using models of the atmosphere (i.e. MODTRAN) and information about the sensor, DIRSIG is able to output a radiance field image that accurately predicts the output radiance found in many natural scenes.

Imaging systems like DIRSIG are beneficial because they allow for a large range of scenarios or setups to be tested with out the need for a large data collection. This creates a reduction in the amount of spending and time necessary to go into the field. DIRSIG may also be used to test scenarios that cover a large area (miles) and would be difficult to replicate.

Algorithms such as those used for detection can also be tested on DIRSIG images. DIRSIG images without the sensor in place may be treated than as truth, allowing you to test the abilities of the sensor. Modeling systems like DIRSIG allow you to step backwards and forwards through the imaging system, so that if an error occurs you are aware of what the input was and are able to identify areas that may be malfunctioning. Synthetic image generators also allow for the development and testing of new sensors prior to the initial cost of building them.

The goal of synthetic modeling systems like DIRSIG is to obtain data that is as analogous to true data as possible. In order to obtain realistic results, both spectral and spatial properties of targets must be modeled correctly. The progression of DIRSIG since its first appearance has been to increase the quality of its output. DIRSIG seeks to generate synthetic images that are very similar spatially and spectrally to real objects.

Consider the spatial characteristics of a grass target. The target appears to be textured, but what exactly is it that causes the textured appearance? Individual blades of grass have slightly different reflectance spectra. It is variations in these reflectance spectra that produce the textured appearance of grass. While the spectra are not the same, they are, however, related and contain a certain set of statistics that characterizes a grass target.

In order for DIRSIG to correctly classify a class, it is very important for the model to use the correct statistical relationship for a grass target. Failure to do this may cause noise in the image or result in a misclassification. This research project will examine the current techniques implemented by DIRSIG in characterizing the texture of a grass target.

Texture in DIRSIG is applied to each pixel spectrally\textsuperscript{3}. Currently this is accomplished by examining the image over a certain range of wavelengths to determine which spectra from a database of 100 spectra is a best fit. DIRSIG does this through a mathematical examination of the reflectance spectra in the grass database. The inputted texture image (grayscale) for the grass target is quantified statistically through a measurement of mean and standard deviation in gray value and a z-score is calculated for each of the pixels\textsuperscript{3}.

This information is transformed into reflectance data. Due to their interdependence, z-scores are computed for each grass spectra in the database, for the given range of wavelengths and the
The closest reflectance spectra is chosen to represent that pixel in the target. This data is then used for any wavelength of the given pixel. This relationship is described in Figure 13.

Figure 13: Illustration for determining the spectra for a given pixel

While Figure 13 accurately demonstrates the current technique employed by DIRSIG to choose the spectra for a given pixel of the grass target, it also demonstrates the flaw in this technique. Consider the range over which the z-scores are compared. It is in this region that the spectrum with the closest z-score value is chosen. The curve with the closest Z score is now used to describe the entire reflectance spectrum for that pixel, over the entire range of wavelengths.

Figure 13 shows the variations in the different spectra throughout the entire range of wavelengths. It is apparent that while some of the curves have the same shape in the region of interest, they may vary immensely in shape in other regions of the spectrum. Using this technique we may choose a reflectance spectrum that looks very much like grass in this bandpass, but does not match the real texture characteristics in the infrared wavelengths.

This is similar to comparing a piece of music at only one frequency. Songs may have the same sound in certain frequencies but sound completely different in many other frequencies. Another description of this is metamerism, looking at a target's color under one type of lighting two colors may look similar, while under different lighting they may look tremendously different.

This project will examine the current techniques that are used by DIRSIG for the texture characterization of grass and determine the quality of these results by comparing them to a truth image of grass. The hypothesis is that the results produced by the current techniques will not be as good as is desired and possible methods for improvement will be examined. The effect of expanding the spectral database for grass targets in DIRSIG will be tested in order to determine if a significant improvement is apparent.

An algorithm will be implemented in DIRSIG that focuses on two additional areas of the reflectance spectrum and compares two additional z-scores when mapping the spectra from the database for each pixel of grass. This method will be tested to determine if it has contributed a
significant improvement in the resulting image's quality. If these two techniques fail to provide significant improvement in quality, further research will be done on texture characterization and implementation for synthetic image generation.

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Methods

OVERVIEW

DIRSIG stands for Digital Imaging and Remote Sensing Image Generation Model; it is a synthetic image generation system. The goal of this project is to provide an assessment of DIRSIG’s texture characterization techniques for a grass target. DIRSIG will be used to generate a synthetic image of grass, which will then be compared to a truth image of grass. In an attempt to improve the DIRSIG output, an investigation will be done into different techniques that may be employed to change DIRSIG’s texture characterization routines.

Distinct methods that will be examined include expanding DIRSIG’s database of spectra for grass targets. The results of these methods will be tested against the truth data and compared with DIRSIG’s current method for the texture characterization of a grass target. Research will concentrate in part on developing an algorithm that examines two additional areas of the reflectance spectra. Z-scores in three different areas will be compared to determine which spectra should be mapped into a particular grass pixel.

The goal of this research is to assess the current techniques used by DIRSIG and to investigate the effects that several alternate or additional techniques have on the quality of DIRSIG’s outputs. A significant amount of research will be done on texture characterization techniques for synthetic images in an attempt to determine a better technique to be implemented into DIRSIG.

ASSESSMENT

The Target

The target examined in this research is a grass target. A grass target was chosen because of the high variance that exists within images of grass; there are also many real world applications that apply to the imaging of grass as part of a scene.

Acquisition of Images

In order to make an assessment of DIRSIG’s texture characterization techniques, there must be a truth image to compare with DIRSIG’s synthetic imagery. Two scenes were chosen as test scenes to be simulated in DIRSIG in order to incorporate two different methods for building a spectral database. The first was an image taken by the airborne spectrometer MISI. A subsection of the image was taken; it was selected to include only a grass target. An image taken by the airborne sensor HYDICE was the second image examined, once again a subset of the image containing only a grass target was used. Both images were obtained from the Digital Image and Remote Sensing group at Rochester Institute of Technology.
Simulation of MISI in DIRSIG

A specific MISI image was simulated in DIRSIG; spectral data for the database to be used with this scene was collected using a hand held spectrometer. A model of the MISI airborne hyperspectral imaging spectrometer was incorporated into DIRSIG in order to simulate real world data. The generated DIRSIG images of grass were then tested utilizing ENVI’s Principle Components analysis in order to determine the quality of the DIRSIG image, results for the DIRSIG image were then compared with results found for a MISI image taken under the same conditions of the same spectra.

The generated DIRSIG image of grass was tested utilizing ENVI’s Principle Components analysis in order to determine the quality of the DIRSIG image. The DIRSIG image was then compared with those found for the MISI image of real grass. Once the quality of the DIRSIG image was quantized, distinct methods were employed to change DIRSIG’s texture characterization routines in an attempt to improve the model’s output.

Simulation of HYDICE in DIRSIG

The second scene that was used was that of a HYDICE image. In this case the spectra for DIRSIG’s spectral database were extracted directly from the scene data. This created an optimal set up for testing DIRSIG’s routines, since we knew that an exact fit for the spectra at each pixel existed within the spectral database. In this manor we were able to test DIRSIG’s ability to map these curves to the appropriate pixel. The spectral database was incorporated into a DIRSIG run with available models for the HYDICE sensor. The DIRSIG output image was then compared to the actual HYDICE image using ENVI’s Principle Components analysis.

METHODS FOR IMPROVEMENT

Once the quality of the DIRSIG image has been assessed, distinct methods were employed to change DIRSIG’s texture characterization routines in an attempt to improve the model’s output. The improved methods that were employed included doubling the size of DIRSIG’s spectral database for grass targets and creating an improved z-score algorithm that was implemented in DIRSIG. This algorithm checks z-score statistics in two additional regions of the reflectance spectra in addition to the bandpass that DIRSIG was previously using, in order to determine which spectra in the database will be used to characterize a pixel of grass.

Expanding DIRSIG’s Spectral Database

In the Simulation of MISI

In the simulation of the MISI image, the spectral database was made up of the original set of thirty spectra that was collected for the grass target. In order to examine what effect the size of the spectral database would have on the quality of the DIRSIG image, the spectral database was expanded. A supporting utility for DIRSIG, expand_emissivity_file2, was used to accomplish this. This procedure uses the input emissivity curves to generate another set of curves, the number of
curves the user determines, that have the same multi-spectral statistics as the original set. The spectral database for MISI was expanded from a set of thirty curves to a set of two hundred.

In the Simulation of HYDICE

In the simulation of the HYDICE image, spectra for the database were extracted directly from the scene. In order to assess DIRSIG’s ability to create a set of spectra that correspond accordingly, the expand_emissivity_file utility was used again in order to create two separate sets of curves to be tested in DIRSIG. The original extracted set of reflectance curves consisted of two hundred and fifty six curves. The first set of spectra that was constructed using the expand_emissivity_file utility was composed of ten spectra. The second set was constructed to have the same number of curves as the set that was originally extracted.

Incorporation of Additional Bandpass Regions

DIRSIG applies texture to each pixel spectrally. Current techniques use a texture image taken from one bandpass to select a reflectance curve from a large database of reflectance curves in order to represent the spectral variations within the given material. Means and standard deviations are used to calculate z-scores for both the grayscale texture image and for each curve in the database over the same bandpass. Z-scores are compared to select a curve. Once a curve is selected, that reflectance curve is utilized in the computations for the given pixel in any spectral region being modeled.

First, a quantitative measurement is made of the texture image that the user has imputed. This quantitative measurement is made through statistical means. The average mean and standard deviation are computed for the texture image. For each pixel in the grayscale texture image, the brightness is used in the form of the pixel's digital count, in order to calculate a z-score for that pixel in the texture image, as shown in Equation 1.

\[
 z_i = \frac{(Dc_{ij} - \mu_{\text{texture}})}{\sigma_{\text{texture}}} 
\]

Equation (1)

DIRSIG relates the spectral database of curves to the texture image by examining each of the curves in the same bandpass region that the texture image was taken. For the reflectance database, a method for comparison was derived that ranked each curve according to their relationship to the mean of the family of curves. The mean reflectance value of each curve was computed as described in Equation 2:

\[
 \rho_{\text{avg},i} = \frac{\sum_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} \rho_{\lambda,j}}{n_i} 
\]

Equation (2)

Note: \( N \) is the number of curves; \( i = 1, N \) where \( s_{\text{avg},i} \) is the average reflectance over the bandpass from \( \lambda_{\text{min}} \) to \( \lambda_{\text{max}} \) curve \( i \) in the set of \( N \) curves, \( n_i \) is the spectral reflectance for the \( i^{th} \) curve at \( \lambda \), and \( n_i \) is the number of points across the bandpass for the \( i^{th} \) curve.
The mean and standard deviation for the bandpass averages are then computed as described in Equation 3 and Equation 4.

Equation (3) \[ \rho_{\text{avg}} = \frac{1}{N} \sum_{i=1}^{N} \rho_{\text{avg},i} \]

Equation (4) \[ \sigma_{\rho} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\rho_{\text{avg},i} - \rho_{\text{avg}})^2} \]

The Z-score for a curve, i, is then calculated as described in Equation 5:

Equation (5) \[ Z_i = \frac{\rho_{\text{avg},i} - \rho_{\text{avg}}}{\sigma_{\rho}} \]

The incorporation of additional bandpass regions utilized the use of multiple bandpass regions with this current technique. For each bandpass to be examined, a texture image was created in DIRSIG. These bands were then specified in DIRSIG using the current technique for the input of one texture band. This resulted in a list of z-scores to be examined for each spectrum in the database, DIRSIG then selects the spectra that fits all of the bandpass regions most closely. This results in a list of parameters for DIRSIG to fit for a spectrum instead of the one parameter that it was examining before. In this way a number of regions could be examined to ensure that the accuracy in one region was not disregarded due to the need for accuracy in another. The use of one, two, and three bandpasses in DIRSIG’s texture characterization routines were examined for comparison.
Results

OVERVIEW

This research has quantitatively examined the ability of DIRSIG to replicate real world texture characteristics, specifically for a grass target. Research discovered a large gap between the amount of information that is contained in images of real world data and the synthetic images that were generated by DIRSIG. Expanding the spectral database did produce a slight increase in results, increasing the qualitative appearance of the image as well. Still, the amount of data contained in the DIRSIG image remained significantly less than that contained in the real image. Increasing the number of bandpasses employed by DIRSIG in determining which spectra to map onto a particular pixel, resulted in two different concepts.

Adding one bandpass increased the ability of DIRSIG to map correctly the most appropriate spectra. Additional bandpasses may increase the quality of an image, however, choosing too many bandpass regions for an image can cause the resulting quality of the image to decrease. The process is very complex, the output quality is dependent on the particular imaging system that is being modeled, the bandpasses that are chosen, and the amount of bandpasses that are used as references.

The conclusion of my research is that while the quality of the image is increased, more research must be done into texture characterization techniques, and the current methods of texture characterization may have to be greatly changed in order to obtain any significant increase in the quality of the DIRSIG images. Also a much closer examination in to the particular band regions examined may provide a greater understanding on how multiple bands may be used together more effectively.

ASSESSMENT

Simulation of MlSI in DIRSIG

MlSI was simulated in DIRSIG through the incorporation of MlSI response files into the DIRSIG's configuration file. The response files were generated by inputting data from MlSI's response curves. The Digital Image and Remote Sensing group at the Rochester Institute of Technology provided information for the response curves. Spectra for DIRSIG's database were taken from grass spectra that were recorded as ground truth during the MlSI acquisition flight we were attempting to simulate. The MlSI sensor was successfully incorporated into DIRSIG, however the simulation of MlSI data was determined to have low quality. This was due to the lack in variance of the curves used in the spectral database. The curve set used was taken while held over one particular area of grass. While thirty curves were generated, these curves varied slightly from each other when compared. A second set of field data was input into the spectral database, and the same error was found with this acquired data. Techniques for ground truth acquisition do not incorporate the acquisition of grass spectra over a large area of grass, and were therefore lacking in needed variance.

Simulation of HYDICE in DIRSIG

Spectra for DIRSIG's spectral database were successfully extracted from the HYDICE scene.
data. A previously implemented HYDICE model was used for HYDICE runs. The HYDICE data provided for a more accurate analysis of DIRSIG’s abilities. The fact that the spectrum was derived directly from the scene ensured that there was an appropriate curve for each pixel. This produced a more accurate test for DIRSIG's ability to match the correct curve within it's database to a given pixel since we knew that there was a perfect match for each pixel in the image provided in the database. When a principle components analysis was completed on both the HYDICE image, and the DIRSIG simulation, even with the extracted scene spectra there was a definite difference in the amount of information contained in the images. The DIRSIG image was found to contain a far lesser amount of information than the HYDICE image.

METHODS FOR IMPROVEMENT

Once the quality of the DIRSIG image was assessed, the distinct methods that were employed to change DIRSIG's texture characterization routines were evaluated. While all of these routines did create an improvement in the quality of the DIRSIG image, the principal components analysis’s that were done, revealed a significant difference between the synthesized and real images in each case. However, more important than the quantized values for the images, several of the techniques produced an increase in image quality that while not described by the numbers of the image, are quite apparent visually. This result alludes to the complexity of texture itself, the reason why it was so closely examined in this research. While the numbers may show no significant change, a great change is apparent within the images.

Expanding DIRSIG's Spectral Database

Expanding the spectral library was ineffective in improving the quality of DIRSIG's MISI simulation due to the fact that the reference spectra did not contain enough variance. A second acquisition of ground truth was completed in the hopes to provide a more variant database. Once again the ground truth was found to lack the variance that would be required to successfully measure the difference between the two databases. While the curve set was expanded from thirty to two hundred, the base set of curves that was used for the statistical comparison, was to similar to produce a curve set with a high enough variance to significantly effect the results.

For the HYDICE simulation, the original extracted set of reflectance curves consisted of two hundred and fifty six curves. This set of curves was than used with the `expand_emissivity_file2` utility to generate a DIRSIG database of ten spectra. The extracted HYDICE spectra was than also used in order to construct a database with the same number of curves as the set that was originally extracted, in this way to test DIRIG's simulation of the statistics and it's effects on the image quality. Figure 2a shows the resulting images for expanding the database, and the DIRSIG image generated with the original extracted spectra.

Figure 2a: HYDICE Results for Expanded Database Sets
Comparing the two images generated with expanded emissivity files on the right with the image generated using the HYDICE extracted spectra on the left, we can qualitatively examine the effect that the size of the database has on the quality of the DIRSIG output. Image B replicates some of the larger artifacts found in image A, but fails to replicate a lot of the detail. Image C, which was generated with the larger spectral database, demonstrates the increase in structure that is found with a larger set of spectra to select from. A careful examination of the right side of the images could be used as one example to illustrate the increase in quality of the DIRSIG image due to a larger database. In image B, many areas are dark that are not in image A. The decreased number of spectra in the database in image B causes an apparent decrease in the detail of the image. This decreases ability of DIRSIG to replicate the structure that is present in the real image.

While the DIRSIG image with the larger database does reconstruct a large amount of the structure of the texture more accurately, it fails to completely reproduce the structure found in the original image. Even the DIRSIG image produced using the extracted spectra for it's database has a great difference from the actually HYDICE image. Figure 2b, allows us to look closely at these two images side by side. The high quality spatial and spectral variance found in the HYDICE image is not contained in the DIRSIG simulation. Image E does demonstrate the capability that DIRSIG has of incorporating high amounts of spatial and spectral variation, while also demonstrating the fact that it still falls short of replicating the complex spatial and spectral variations found in the real image.

Figure 2b: HYDICE Image vs. DIRSIG Simulation
Incorporation of Additional Bandpass Regions

The spatial pattern (texture) of a material will vary as a function of wavelength. Images of the same area of grass at different wavelengths are not the same. We want to be able to introduce spatial and spectral variations (texture) to a modeled material. This method for improvement considered the fact that usually images of the material exist for a few spectral bands. Current techniques utilized by DIRSIG made use of only one of these images as a texture band. The use of only one band meant that the spectral database was matched by using the data for that spectral region only. The spectrum that was chosen based on that bandpass region was than used for all bandpass regions of the given pixel. Considering the addition of other bandpass regions allowed us to compare the spectra in different areas of the curve. The theory was that by adding more spectral bandpass, DIRSIG would be better able to match the entire shape of the curve for one pixel.

Two additional bandpass region were incorporated into DIRSIG’s current techniques for mapping texture. For each bandpass to be examined, a texture image was created in DIRSIG. These bands were than specified in DIRSIG using the current technique for the input of one texture band. This resulted in a list of z-scores to be examined for each spectrum in the database, DIRSIG than selects the spectra that fits all of the bandpass regions most closely. This results in a list of parameters for DIRSIG to fit for a spectrum instead of the one parameter that it was examining before. In this way a number of regions could be examined to ensure that the accuracy in one region was not disregarded due to the need for accuracy in another.

Statistical Analysis

In order to analyze the information contained in each DIRSIG image, to quantify the results, ENVI’s Principle Components Analysis was utilized. The forward PC rotation uses a linear transform to maximize the variance of the data through statistical means. This transformation can be used in order to determine the amount of information that is contained within each band of an image. Table one is a chart that displays the normalized eigen values for DIRSIG images with multiple bands.

Table 1: Compressed Table of Normalized Eigen Values for the Comparison of DIRSIG (with multiple band runs) and HYDICE data.
<table>
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<tr>
<th>DIRSIG Band Number</th>
<th>DIRSIG Wavelength (nm)</th>
<th>DIRSIG Wavelength (nm)</th>
<th>HYDICE</th>
<th>DIRSIG One Band</th>
<th>DIRSIG Two Bands</th>
<th>DIRSIG Three Bands</th>
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<td>394.214</td>
<td>1</td>
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<td>6.32E-07</td>
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</tbody>
</table>

The normalized eigen values in the table are used to measure the amount of data contained in the DIRSIG images for each of the runs at certain wavelengths. Eigen values for the HYDICE image are also included in the table, in order to demonstrate the relationship that existed between the numbers of wavelength ranges that contained in the DIRSIG images, to the number that contained information in the truth image, the HYDICE image. For the truth image there is information contained over every bandpass, the DIRSIG images fall short of accomplishing this. The results of the principle components analysis for the images indicate that there is a great gap in the amount of
information that can be found in the HYDICE image, and the amount of information that contained in any of the DIRSIG images. The maximum eigen value for the HYDICE image was 8,649,461. The maximum eigen values for the DIRSIG images showed a significant difference in the amount of information present within the images.

Adding a second bandpass region did create a slight increase in the eigen values, but it fell far short of bridging the gap of informational content that exists between the synthetic data and real world data. With the use of two regions, the amount of information contained in the image covers a wider range of wavelengths. After the addition of the third bandpass region, the amount of information within the image decreased, as did the range of bandpasses that contained useful data. This system for selecting and attempting to reconstruct texture is very complex. The number of different combinations of texture bandpasses that could be utilized was very large. Many factors could be used in real world scenarios to determine which bandpass regions to use, such as, wavelengths that would be examined by the sensor or algorithms to be tested, the bandpasses that were available for texture images, and the reliability of those bandpass regions (some bandpass regions may contain distortions caused by, for instance, water absorption features).

After a examining the HYDICE image in order to determine which band numbers to use, three bandpass regions were identified that appeared to be images that were good examples of structured texture, and contained data that the other bandpass regions did not. The three bands used in this research as texture bands were: Band #1 (0.431 microns), Band #2 (0.828 microns), and Band #3 (1.260 microns). The texture band used in the single DIRSIG run was at 431 nm, the run with a second band also included the 828 nm texture band, and finally, the DIRSIG run with three bands incorporated the texture bands for all three of the wavelengths (431 nm, 828 nm, 1260 nm).

Figure 3: A Comparison of Normalized Eigen Values vs. Wavelength Plots for Multiband DIRSIG Runs.
Figure three demonstrates the difference that exists in the Eigen values found for DIRSIG runs with or without multiple bands. When comparing the DIRSIG runs with the HYDICE data, an obvious shift in the eigen values for all of the DIRSIG runs toward lower wavelengths is clearly apparent.

Qualitative Visual Analysis

The greatest difference in the results found by incorporating the use of additional bandpasses is demonstrated not quantitatively by a table of numbers, but through a qualitative examination of the resulting images. It was very difficult to gain an understanding of the texture contained within an image using quantitative measurements. The greatest indication of the effect that increasing the number of bandpass regions DIRSIG incorporates has on the images, was to do a simple visual inspection and comparison of the images. The resulting images for these three runs were examined over several wavelengths for a comparison with the original HYDICE image. Figure three shows the DIRSIG images for the several runs side by side next to the HYDICE image.

Figure 4: Resulting Image Comparison for Use of Multiple Bandpasses in Image Generation

<table>
<thead>
<tr>
<th>Truth Image: HYDICE</th>
<th>DIRSIG One Band Run</th>
<th>DIRSIG Two Band Run</th>
<th>DIRSIG Three Band Run</th>
</tr>
</thead>
</table>

Figure 4a: Band #10 (0.431 microns)
The image on the left in Figure 3a is the HYDICE image of the grass scene that was reproduced in DIRSIG. The DIRSIG images are to the right of it. When visually inspecting these images, there is an apparent structure to the grass image produced by HYDICE. The DIRSIG run using one texture image, or comparing one bandpass shows some of the same spectral structure, however, when a second bandpass is added, the texture in the image is noticeably closer to that of the HYDICE image. Adding a third bandpass at this wavelength seems to deteriorate the structure of the texture in the DIRSIG image, once again making it less similar to the HYDICE image.

**Figure 4b: Band #66 (0.828 microns):**

Inspecting the image at different wavelengths will give us more information on how well the chosen spectra matches over a broad range of wavelengths. Once again, in the set of images in figure 3b, it is apparent that the DIRSIG image created with the use of two texture bands more closely replicates the visual texture properties of the HYDICE image to the left. A comparison of these images suggests that the texture in the two-band image has texture that is structured more similarly to that of the HYDICE image. In the image generated using one texture band, this texture is less apparent. The image to the far left, generated using three texture bands, once again seems to indicate that the third additional band is causing a break down of the textural structure.

**Figure 4c: Band #96 (1.260 microns):**

It is apparent that at this wavelength, that the HYDICE image is best reproduced when two bands are used. The lower left hand corner of the images can be identified as one region in which details found in the HYDICE image are replicated in the two-band image but are lost in the three-band image. The one band image fails to reproduce the same amount of detail as the two band and three band images.

**Figure 4d: Band #124 (1.643 microns):**
The second image, created using one texture band in DIRSIG shows an obvious lack of textural structure, the third image which was completed using two texture bands in DIRSIG and shows a definite increase in the structure of the texture in the resulting DIRSIG image. When closely comparing this image, and the last image to the original HYDICE image on the left, in this case, the image generated using three texture bands matches the texture more closely. This could be due to the wavelength which is being examined, this wavelength, which is closer to that of the third band that was used, than the second or first.
Conclusion

OVERVIEW

This research explored the quality of DIRSIG's simulated images in comparison with real images that were used to obtain truth data. The results of this investigation indicate a great room for improvement of the output that would more accurately represent real data. This calls for a closer examination of DIRSIG's texture application routines, and for alterations to this technique, perhaps even to determine a new technique for the incorporation of texture. Methods for improvement were tested, such as expanding the spectral database, and the alteration of DISIG's texture application method to include additional band pass regions.

QUALITY OF DIRSIG IMAGES

Careful examination and comparison of DIRSIG's output images (before new methods were incorporated), to real image data, revealed a large difference in the amount of information contained within the scene. The principle components analysis revealed that the truth or real image contained data over every wavelength, while the DIRSIG images do not. Also the amount of information continued in the first bandpass was found to be significantly higher for the real image. Thus there was determined to be a large gap in the amount of information produced by DIRSIG for each image.

EXPANDNING THE SPECTRAL DATABASE

The expansion of the spectral yielded an increase in the quality of the output image. A qualitative examination of DIRSIG images generated using both limited and expanded databases were completed, in which the expanded database was determined to demonstrate better replication of the characteristics produced by the texture of grass in the HYDICE image. The image generated using a limited spectral database replicated the large structures fairly well but failed to replicate smaller artifacts. A comparison of the DIRSIG image to the HYDICE image demonstrated that DIRSIG has a limited ability to replicate the entire structure of the grass, even with a large spectral database.

INCORPORATION OF ADDITIONAL BANDPASS REGIONS

There is an apparent shift in the DIRSIG images toward shorter wavelengths; this may be an artifact of DIRSIG's sensor configuration for simulation of HYDICE. Principle components analysis was done on each image to get a quantitative measure of how much information it contained. The results of the principle components analysis for the images indicate that there is a great gap in the amount of information that can be found in the HYDICE image, and the amount of information that contained in any of the DIRSIG images. The maximum eigen value for the HYDICE image was 8,649,461. The maximum eigen values for the DIRSIG images showed a significant difference in the amount of information present within the images. The HYDICE image also contained data over every bandpass, while the DIRSIG images each contained a far lower number of bands containing information.

Using one additional bandpass appeared to create an increase in the eigen values; incorporating two additional bandpass regions actually decreased the eigen values. In each case the increases were quite minor compared to the size of the gap that exists in the level of information found in the image. Regardless of the number of bandpasses used, the DIRSIG image still was found to contain
a significantly less amount of data than that contained in the HYDICE image. A qualitative examination of the resulting images revealed more clearly the improvements that adding a second bandpass had on the structure of grass in the DIRSIG image.

**FINAL RESEARCH ASSESMENT**

The amount of information contained in the DIRSIG images that were examined showed a continual and significant difference from that of a real image. The methods for improvement tested through this research did show certain levels of quantitative improvement, however this improvement was minor. Qualitatively, when examining the appearance of the DIRSIG images, DIRSIG's ability to replicate the artifacts found in the real image of grass were significantly improved with both the expanding of the spectral database and the addition of a second bandpass region.

DIRSIG's system for selecting and attempting to reconstruct texture is extremely complex. There is a large number of bandpasses that may be used to create texture images, and these may be used in an even larger number of combinations. Determining which combination would work more effectively is a very difficult task. The factors that could be used in real life to determine which bandpass regions are numerous, the most frequent probably being based on which bandpass region are the scenario would be most concerned with. This research suggests a need for a closer look at the information that each bandpass regions contains, and how these bandpass regions interact with one another.

This research, while showing a great difference in the quality of DIRSIG's images, has pointed a continuous and large discrepancy in the quantitative replication of texture in the simulated image. The next step would be to research the effect that the lack of this significant amount information has within the various systems to be used, and if there is another viable method for generating the texture that would be compatible with DIRSIG.

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