A Unified Model for the Information Content of Remote Sensing Imagery

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Abstract—**The information content in remote sensing imagery depends upon various factors such as spatial and radiometric resolutions, spatial scale of the features to be imaged, radiometric contrast between different target types, and the type and amount of noise present in the imagery. Various statistical and textural measures are used to characterize image information content, based upon which different image processing techniques are employed to quantify this parameter. Previous work in this area have resulted in three different approaches for quantifying the image information content, primarily based on interpretability, mutual information, and entropy. These approaches, although well refined, are difficult to apply to all types of remote sensing imagery. We have developed an approach based on the use of classification accuracy to quantify image information content, since loss of information occurs if pixels in the image are wrongly classified. Using this approach, we have separately developed negative exponential models relating information content to image parameters such as spatial and spectral resolution.**

In this paper, we describe a preliminary unified information content model and assess its performance using hyperspectral AVIRIS imagery. The model combines the effects of the above parameters and takes into account the interrelationships between them with respect to information contained within the image. Using the model, appropriate trade-offs between the parameters can be investigated for obtaining a specific value for image information content for a particular application.

I. Introduction

Various textural measures are used to characterize the image information content. Previous work in this area have resulted in three different approaches for quantifying the image information content, primarily based on interpretability, mutual information, and entropy [1]-[2]. These approaches, although well-refined, are difficult to apply to all types of remote sensing imagery. In a majority of cases, the raw image acquired by the sensor is processed using various operations such as filtering, compression, enhancement, etc. In performing these operations, the analyst is attempting to maximize the information content in the image to fulfill the end objective.

As the spatial resolution and the dimensionality of imagery decreases, one might expect that the information content of the imagery would correspondingly decrease. However, in remote sensing images there may not be as great a loss as we might expect. This can be attributed to the fact that, although the value of a pixel may change as a result of differing spatial or spectral resolution, the same pixel may in some cases, be correctly classified [3]. Thus, an understanding of the effects of spatial and spectral resolution on image quality and interpretability is important from the standpoint of user end applications.

The following empirical model for information content was developed related to the spatial resolution [4]

$$I = exp\{-k(\Delta R)^n\}. \tag{1}$$

In (1), I is the image information content, ΔR is the change in the spatial resolution, and k and n are best-fit sensor specific constants.

The information content thus obtained can be considered to represent an utility index ranging from 0 to 1. The model was developed based on the assumption that the reference image or "ground-truth" is the classified image using all available bands and without changes to the nominal spatial resolution. Maximum achievable information is that value of I obtained from the reference image with the number of classes remaining constant. The model formulation is intuitively appealing, since for $\Delta R = 0$, $I = 1$, i.e., all the information is preserved, while for increasing values of ΔR, there is a decrease in the information. The development of a model which accounts for the combined effects of spatial and spectral resolution is currently being explored.

II. Analysis Procedure

The method of information content analysis for the spatial resolution case consisted of the following steps: (1) Choose the bands in the original image to be used for generating the classified image; (2) Perform an unsupervised classification of the chosen bands of the original image by using the K-means approach for five classes; (3) Obtain the "ground-truth" or reference image from classification using the original unmodified bands; (4) For each band, alter the image by applying a block averaging filter of window size $\Delta R \times \Delta R$ and reclassify the image; (5) Compare the degraded image with the reference image to obtain the actual information content I; (6) Plot I obtained versus ΔR; (7) Determine the best-fit constants k and n; (8) Substitute the values of k and n in the model to generate

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a plot of I versus ΔR; and (9) Compare the plots from steps (6) and (7) to determine the accuracy of the model.

The same procedure is repeated for the spectral resolution case. Adjacent bands are averaged together to implement dimensionality reduction. The reduced spectral resolution images are reclassified and again compared to the reference image to determine the information content. A similar analysis is performed when both the spatial and spectral resolutions are simultaneously degraded. Since we are investigating the interpretability of classified remote sensing images, we need to compare the reference image with the classified degraded image to ascertain the latter's information content. The pixel values in the modified images will change depending upon the extent of the spatial and spectral resolution reductions. A loss in information would occur whenever a pixel in the classified degraded image is misclassified in comparison to the same pixel in the reference image. Hence classification accuracy would be a good measure of information content, I. A value of $I = 1$ indicates that the classified degraded image is identical in interpretability to the reference image, while $I = 0$ indicates that the classified degraded image has no interpretability value for the scene that it represents.

III. Data and Site Description

The scene selected for the information content analysis is shown in Fig. 1. The image is a color composite taken near Moffett Field, California from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) on 9 July 1997. The image is comprised of bands 10, 20, and 30. The scene shows the southern end of San Francisco Bay and the San Francisco Bay National Wildlife Refuge. The scene also includes a portion of the city of Sunnyvale and several salt evaporation ponds. The AVIRIS data examined contained 224 10-nm wide spectral bands ranging from 370 nm to 2500 nm. Of the 224 bands, 193 were deemed to be of acceptable quality for analysis. Each band contained 614 samples and 512 lines of data. The AVIRIS data had a spatial resolution of 20 m and were recorded as 12-bit integers.

IV. Information Content Model Results

To examine the effects of changes in the spatial resolution on the information content, the plot shown in Fig. 2 was generated. Window sizes for the block averaging of 2×2 to 11×11 were used to degrade the spatial resolution. As the number of spatial averages increases, the relative classification accuracy (information content) decreases. By decreasing the spatial resolution, the distinctiveness between individual features becomes less defined and as a result, classification errors occur. This is observed to be the case in Fig. 2. If the model of (1) is applied, values of k= 0.318 and n= 0.3051 were found to best fit the data as shown in the figure.

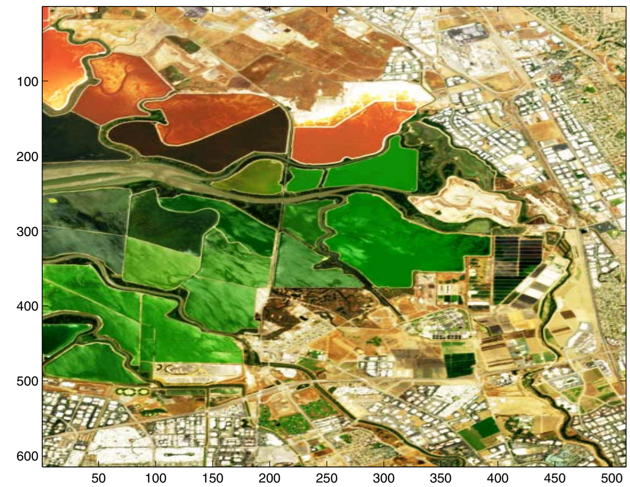

Fig. 1. Color composite of AVIRIS data taken near Moffett Field, California.

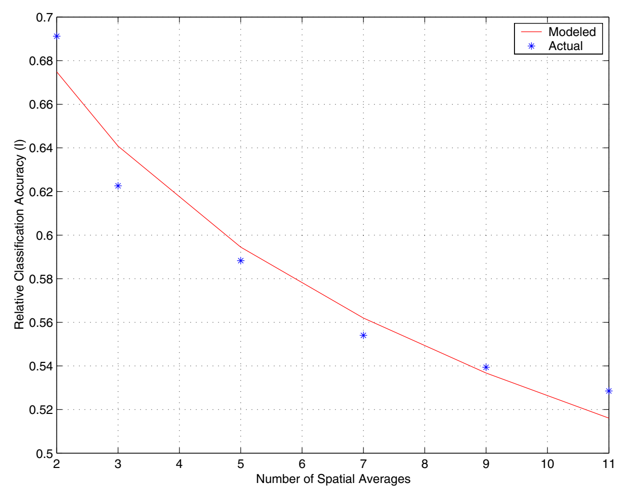

Fig. 2. Comparison of the model given by (1) to the changes in the spatial resolution.

Similarly to the spatial resolution case, the information content as related to changes in the spectral resolution was explored. By averaging adjacent bands, the dimensionality was reduced (by a factor of two) from 96 bands with two averages to four bands with 48 averages with rounding to an even number of bands. The results of the analysis are shown in Fig. 3. The classification accuracy falls rapidly as the number of spectral averages increases beyond six, but then tends to flatten out as the loss of information saturates at about 12 spectral averages.

The combined effects of spatial and spectral averaging are shown in Fig. 4 for four values of spectral averaging. The general shape of the curves follows that observed in Fig. 2. It is apparent that the spatial resolution changes tend to dominate the classification accuracy response for

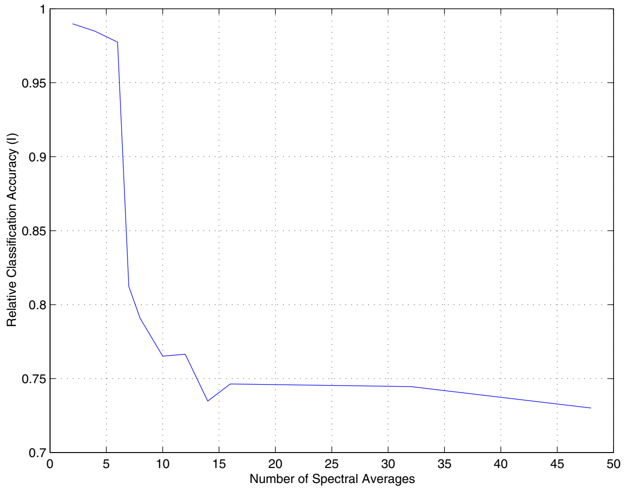

Fig. 3. Relative classification accuracy (information content) as a function of changes in spectral resolution.

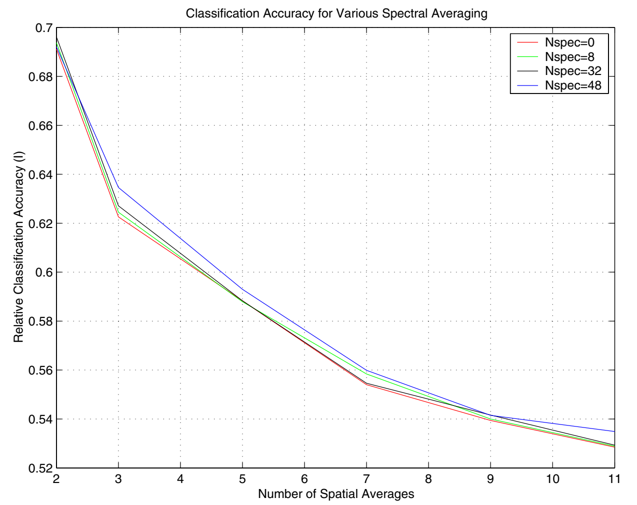

Fig. 4. Relative classification accuracy for combined spatial and spectral resolution changes.

these cases. It is interesting to note, however, that the relative classification accuracy increases by up to one percent for increasing spectral averaging. This may be a result of the peaking effect observed in hyperspectral classification in which the accuracy maximizes and then may fall for an increasing number of dimensions. The results may also be related to the number of user assigned clusters given to the classifier. Modeling of the combined effects is currently being explored to develop a function relating both spatial and spectral resolutions. One method under investigation is to develop a multiplicative model assuming that the information content relationships are independent for the spatial and spectral resolution cases. The contributions of each individual band by use of a principal component analysis could be used to determine an appropriate dimensionality reduction to maximize the information content.

V. Conclusions

This paper has shown the effects of spatial and spectral resolution changes on the information content of AVIRIS data. A model was developed for spatial resolution changes as related to relative classification accuracy. Combined spatial and spectral degradations were shown exhibit a similar behavior to that of the spatial only case. The development of a unified model incorporating these two variables is currently under study. The model will also account for numerous other information content variables such as radiometric resolution, noise, and target size based on the user end application.

References

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