Information Content Characterization in Remote Sensing Imagery Based on Classification Accuracy

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Abstract— The information content in remote sensing imagery depends upon various factors. Various textural measures are used to characterize the image information content. Our approach to quantifying image information content is based upon classification accuracy. We have developed a negative-exponential model that relates information content to spatial resolution, which is seen to be applicable to real images acquired by Landsat TM optical as well as SIR-C SAR sensors. An interesting conclusion that emerges is that although the TM image has higher information content than the SIR-C image at lower pixel sizes, the opposite is true at higher pixel sizes. The transition occurs at a pixel size of about 720 meters. This tells us that for applications that require higher resolutions (or smaller pixel sizes), the TM sensor is more useful for terrain classification. On the contrary, for applications involving lower resolutions (or larger pixel sizes), the SIR-C sensor has an advantage. Thus, the model is useful in comparing different sensor types for different applications.

INTRODUCTION

Typical examples of the use of remote sensing imagery include estimation of soil moisture, delineation of ice-water boundaries, and identification of targets concealed in clutter backgrounds. The raw image acquired by the sensor is processed using various operations such as filtering, compression, enhancement, etc., in order to maximize its information content. The information content in an image must first be quantified and related to the end objective. The image information content is a function of several variables, such as the spatial resolution, the radiometric resolution, the scale of variability of the physical parameter of interest, the radiometric separation between two different classes of targets, as well as the ultimate objective of the image analysis (i.e., target detection vs. edge delineation)

In this study, we explore the relationship between information content and spatial resolution. Previous work on this topic have resulted in three different approaches for quantifying the image information content. The first approach, based on interpretability [1], i.e., the ability to identify different targets at different spatial resolutions, does not use any image data or account for the spatial scale of the target. The second approach, based on mutual information [2], is more applicable to the design of imaging systems for high-fidelity reproduction of imagery upon transmission through a channel. The third approach, based on entropy [3], evaluates information in terms of image variability, without regard to the end application. These approaches, although well-refined, are difficult to apply to all types of applications involving remote sensing imagery.

INFORMATION CONTENT MODEL

We consider the relationship between the information content of an image (in whatever manner it is quantified) to the spatial resolution. As is well-known, smaller the pixel size, better the ability to interpret small scale features within the image, and hence higher the information content value of the image. The information content also depends upon the scale of the feature to be imaged. It is intuitively apparent that larger the size of the target, higher is its detectability, and hence higher the information content of the image. This relationship was originally investigated by Kalmykov et al. [4] in their study comparing the information content of images acquired by different spaceborne SAR sensor systems. Our approach closely follows the above formulation.

As the spatial resolution improves and the pixel size ΔR reduces, the amount of information to delineate the spatial extent of the target, R, increases. We get maximum information when the pixel size has a utopian value of zero, and the information content reduces to zero at pixel size of infinity. The information content from simulated radar images, when plotted versus $\Delta R/R$, showed a negative exponential dependence. Hence, we modeled the information content, I, as a function of pixel size, ΔR, and the target characteristic dimension, R, as [5]

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

where k and n are the parameters related to the interpretability of the image, as well as the contrast between the target and the background. Values of k and n are empirical and our simulations studies provided some clues that allow us to quantify these parameters. The above formulation was intuitively satisfying, since the information content is unity for ΔR=0, and is zero for $\Delta R = \infty$.

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SITE DESCRIPTION

The images used were a part of a large scale hydrological field experiment conducted over the Washita watershed near Chickasha, Oklahoma.

The Landsat TM data used were acquired by USDA ARS located in Durant, Oklahoma. The full image was georegistered by the USDA ARS Hydrology Lab to USDS topographic map from which the primary study area extracted. The spatial resolution obtained was 30 m.

The SIR-C images were simultaneously acquired at two microwave wavelengths: L-band (24 cm) and C-band (6 cm). VV, HH, and VH amplitude images were used. The SIR-C data sets were georeferenced for each day to the TM image using control points. The spatial resolution obtained was also 30 m.

CLASSIFICATION ACCURACY AS A FUNCTION OF SPATIAL RESOLUTION

The analysis of the information content in real images was carried out by using the classification accuracy. The classification accuracy is a reasonable parameter to characterize the information content in an image, because a thematic map contains information about different classes in the scene. Misclassification of pixels tells us that we are losing information about the scene. The idea was based on our simulation results. It was noted that with increasing pixel size, the target was misclassified as background. The study on the simulated data was similar to the evaluation of classification accuracy at various spatial degradations. Hence this measure was used for the SIR-C and TM data, which consisted of many classes. Supervised classification was performed using the *Maximum Likelihood Classifier* (ML).

Since there were no thematic maps for the region at resolution of 30 m, the ground truth image was obtained by classifying the region using both the optical (TM) and microwave (SIR-C) data together as a 12 band image in order to get maximum information about the scene. The 12 band image consists of TM bands 1-7, except for band 6 which is the thermal band, and all three polarizations (HH, HV, VV) for both L and C band SIR-C images. The visible and infrared images of TM and color composite SIR-C images were utilized to develop the training sites for the six spectral classes to be discriminated by the classifier. The six different classes identified are shown in Table I.

First, the "ground truth" image in Figure 1 was obtained using the ML classifier. Note that this is a gray-scale reproduction of a color image. For this, all the 12 bands of data were utilized. The statistics for the classes were obtained from highest resolution images for all the 12 bands. The classification was then performed on all spatially degraded images of different pixel sizes for both optical (TM) images and radar (SIR-C) images separately by using all 6 bands. For classification of the spatially degraded images, the statistics of the highest resolution image (pixel size of 1) were used as the base spectral signature, and the statistics of the degraded images were compared to this base signature. The classification accuracy was calculated by comparing the classified image to the ground truth image, and counting the number of correctly classified pixels in the whole image. The classification accuracy was calculated for both the TM as well as the SIR-C images at different resolutions.

TABLE I

SIX DIFFERENT CLASSES IDENTIFIED IN THE IMAGE DATA

Class	Type
Class 1	Soil
Class 2	Forest
Class 3	Water bodies
Class 4	Urban and Highways
Class 5	Pasture
Class 6	Rangeland

Fig. 1. Ground truth image obtained after classification using both TM and SIR-C images (12 Bands).

The information content model described in (1) was applied to the real data. The values of k and n were calculated by curve fitting. Table II shows the k and n values for both sensor systems. Since the classification accuracy was calculated on per-pixel basis, the parameter R was taken to be equal to 1. The curves plotted for both sensors are shown in Figure 2. The data points are the actual classification accuracy, while the solid line is the curve from (1) using the values of k and n from the Table II. From the plots, it follows that our information content model is indeed applicable to TM and SIR-C data.

We now address the significance of the k and n parameters. The value of k denotes the maximum attainable information content of the system at the best possible spatial resolution, i.e., at ΔR=1. Although $I = 1$ at ΔR=0, this is a purely hypothetical case. At ΔR=1, $I = e^{-k}$; thus, higher the value of k, lower is the maximum attainable information content from the sensor. In the above example, the maximum information content for the TM sensor is 0.893, while for the SIR-C sensor, it is 0.741. On

TABLE II
BEST-FIT MODEL PARAMETER VALUES FOR REAL DATA

Sensor Type	k	n
TM	0.1127	0.3856
SIR-C	0.2996	0.0776

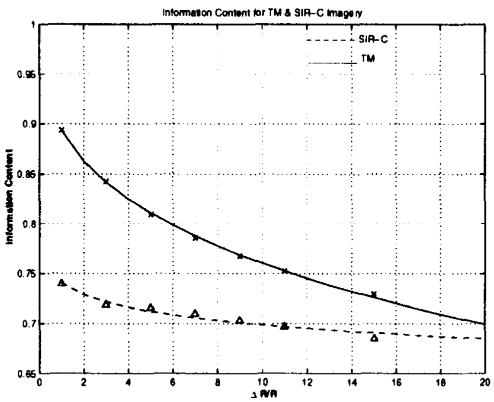

Fig. 2. Plots for the model derived and data points for TM and SIR-C sensors.

the other hand, the parameter n tells us how quickly the information is lost on degrading the spatial resolution for a given k. Higher the value of n, faster is the loss in information content as pixel size increases. In our example, we note that the TM sensor loses information more rapidly than the SIR-C sensor, since it has a higher value of n.

Another interesting fact can be obtained from the k and n values of the TM and SIR-C sensors. By equating the information content of both sensors, we can determine the pixel size at which the plots intersect. By setting

$$exp\left\{-k_{TM}\left(\frac{\Delta R}{R}\right)^{n_{TM}}\right\} = exp\left\{-k_{SIR-C}\left(\frac{\Delta R}{R}\right)^{n_{SIR-C}}\right\}$$

we obtain $\Delta R/R$=23.9 $\approx$ 24. This tells us that at a pixel size of 720 m (24×30 m), the SIR-C sensor has the same classification accuracy as the TM sensor. The information content at a pixel size of 24 for both TM and SIR-C data is computed as 0.68. The classified images at a pixel size of 24 are shown in Figure 3. We conclude that this approach can be used to perform trade-off analysis between sensor systems at different resolutions.

CONCLUSIONS

We note that the classification accuracy follows our information content formulation as regards its relationship to spatial resolution. Our study shows that this formulation can be used to compare different sensor types. According to our model, the TM sensor is suitable for terrain classification under small pixel sizes (less than 720 m), while the SIR-C sensor is better under large pixel sizes (greater than 720 m). Further study will look at integrating the effects of gray scale resolution on the image information content.

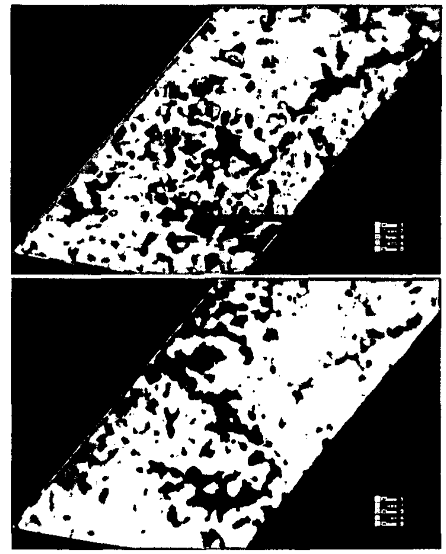

Fig. 3. Classified images of TM and SIR-C at pixel size=24.

ACKNOWLEDGMENT

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