VALIDATION OF A RADIOMETRIC NORMALIZATION PROCEDURE
FOR SATELLITE DERIVED IMAGERY
WITHIN A CHANGE DETECTION FRAMEWORK

by

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INTRODUCTION

Before a time series of remotely sensed imagery can be used in a change detection study, the images must first be standardized for conditions outside of real surface change. Differences in the sensor, solar illumination or atmospheric conditions make it difficult, if not impossible, to accurately compare satellite images acquired on different dates and/or different platforms. The proposed project will establish a validation procedure to evaluate the effectiveness of a previously developed automated technique to normalize temporarily separate but spatially coincident images.

LITERATURE REVIEW

RADIOMETRIC CORRECTION

Several factors independent of ground cover can significantly affect reflectance as measured at the satellite. These include solar elevation, atmospheric conditions and topography. Adjusting imagery for atmospheric attenuation reduces the variation between temporally separate images so they appear to have been acquired under the same solar and atmospheric conditions, allowing for more accurate detection of landscape change. As a result, it is widely recognized that a set of remotely sensed images must be radiometrically normalized before being used in a change detection study. The approaches described here fall into two major categories of radiometric correction, absolute and relative.

Absolute

Absolute radiometric correction takes into account atmospheric conditions (radiative transfer), as well as sensor gains and offsets, solar irradiance, and solar zenith angle at the time of image acquisition to convert satellite measurements to estimate actual
reflectance values as they would have been measured on the ground. Dave (1972, 1978), Fraser et al. (1989), Kaufman (1988), Kniezys et al. (1983, 1988), and Tanre et al. (1990) have all produced atmospheric radiative transfer algorithms which account for the effect of the atmosphere, illumination, and sensor differences.

The algorithm developed by Richter (1990) calculates ground reflectance of each pixel then estimates a correction to account for the influence of neighboring pixels. Richter later developed a two-phase algorithm to work in conjunction with look-up tables containing functions for atmospheric corrections. In the first phase, the user selects a reference target and haze or cloud, and specifies one of the atmospheric functions from the tables. The second phase calculates visibility for the reference areas, removes the haze, then calculates the ground reflectance (corrected for adjacency). This process is spatially adaptive and can be applied to smaller sections of the image for scenes with varying atmospheric conditions (Richter, 1996).

Rahman and Dedieu (1994) describe an atmospheric correction technique, which is faster than radiative transfer algorithms like 5S (Tanre et al., 1990) and is comparable in accuracy. Coefficients correcting for atmospheric influences are determined for specific spectral bands using a set of formulas. Model inputs are vertically integrated gaseous contents, aerosol optical depth at 550nm, geometric conditions and reflectance at the top of the atmosphere (as calculated by their own method). These absolute correction methods tend to be more accurate than relative corrections, but have the disadvantage of being dependant on in situ data which may not be available.
Relative

An alternative to absolute radiometric correction is relative correction, which is commonly used in one of two ways; adjusting bands of data within a single image and normalizing bands in images of multiple dates relative to a reference image (Jensen, 1996).

Single Image

Dark-object subtraction (DOS) is a widely used method of reducing haze within an image and is done for each band individually. It is assumed that there are pixels within each band of a multispectral image that have very low or no reflectance on the ground, and that the difference between the brightness value of these pixels and zero is due to haze. This estimated difference per spectral band is subtracted from each band of the image (Chavez, 1988). As with absolute corrections, this relative normalization method also assumes that the effects of haze are distributed evenly across the entire image, which may not be the case. This is a good primary correction, but the author notes that there may be problems analyzing the data unless one of five atmospheric scattering models (scaled from very clear to very hazy) is chosen in addition to a starting dark-object haze value.

Chavez (1996) further improved the technique of atmospheric correction by adding a multiplicative correction factor for the effect of atmospheric transmittance. This correction is called the COST method and uses the cosine of the solar zenith angle. He compares this method to one that uses in situ field measurements of the atmosphere and finds that the image-based corrections are as accurate as those that require additional information.
Multiple Image

Due to the number of images involved in a multitemporal change detection study and the scarcity of historical atmospheric and ground reflectance data, researchers often opt for a normalization method that corrects a set of images relative to a reference image within the set. Two techniques that have been developed for this purpose are presented here.

One is based on pseudoinvariant features, or features that are assumed to have the same spectral reflectance through the series of images (Schott et al., 1988, Jensen, 1996). Statistical corrections are based on the assumption that the "differences in gray-level distributions of these invariant objects is assumed to be a linear function" (Schott et al., 1988). The ideal pseudoinvariant targets are those that meet the following criteria:

- They are at approximately the same elevation as the rest of the scene (for a better representation of the atmospheric conditions across the scene),
- They are in a relatively flat area (to minimize the effects of solar azimuth differences),
- And should have a minimal amount of vegetation (as vegetation readily changes in response to seasonal changes and environmental stresses) (Eckhardt et al., 1990).

After normalization targets are chosen from the image, the target brightness values from the scenes to be normalized are regressed against the respective target brightness of the reference image. The regression model for each pairing of images consists of an additive component (to account for the difference in path radiance) and a multiplicative component (to correct for differences in detector calibration, sun angle, Earth-sun distance, atmospheric influences and sun-target-sensor geometry between dates (Jensen, 1996). Casselles and Lopez Garcia (1989) also based their work on the concept of
pseudoinvariant features. When tested against a procedure that uses absolute atmospheric
correction, their method differed in accuracy by less than 10 percent.

The other technique is an automatic scattergram controlled regression (ASCR)
method, developed by Elvidge et al. (1995) for use with large sets of Landsat images in
the analysis of land cover change. This method uses near-infrared scattergrams for stable
land and water data clusters to generate an initial regression line. A no-change pixel set is
selected by placing thresholds about this line. These pixels are then used in the regression
analysis of each band to derive gains and offsets for the radiometric normalization.

Requirements for this method are that:

- The images are acquired under similar solar and phenological conditions,
- The land cover for a large portion of the image in the time covered by the
  images to be rectified has not changed,
- And there are both land and water pixels in the scene.

This method proves to significantly reduce haze in the images, making them more
comparable spectrally. The researchers also list advantages of this procedure over other
linear relative normalization methods:

- Cloud/shadow/snow effects are reduced compared with simple regression
  methods.
- A large percentage of the total number of image pixels is used.
- Normalization errors are distributed among different land cover types.
- The necessity of identifying bright and dark radiometric control pixels is
  eliminated.
- The speed of the normalization procedure is accelerated by reducing human
  intervention compared with other empirical methods (though it may not
  reduce the computation time).
Comparisons

A few researchers have reviewed the available correction methods, offered their own, and compared the results of different methods for a single set of images.

Hall et al. (1991) reviewed several correction methods including radiative transfer codes, spectral transforms, sensor calibration, DOS, and pseudoinvariant features, then went on to develop and evaluate Hall and Badhwar's (1987) technique of radiometric normalization. This method is similar to the one described by Jensen (1996), in that radiometric control sets are chosen and a linear transformation is used to adjust the images. Here the bright and dark sets of pixels are selected from Kauth-Thomas greenness-brightness plots (Kauth and Thomas, 1976). The slope and offset of the line that connects their averages are used to determine the coefficients for correction of each band. This technique of atmospheric correction was tested by acquiring helicopter and ground data concurrent with the satellite overpass. They note that large numbers of images can be absolutely corrected in an indirect way, by relative correction of all other images to a reference image, which has sensor calibration and atmospheric data.

Yuan and Elvidge (1996) apply seven different relative radiometric normalization techniques, including the one mentioned above, to two images and compare the results visually and using a standard error statistic. The described techniques are:

- Haze Correction (Chavez 1988)
- Minimum-maximum (adjusting the minimum and maximum histogram values to match a reference image)
- Mean-standard deviation (reference and subject images have the same mean and standard deviation for all bands)
- Simple regression (Jensen, 1983) where the subject image is regressed against the reference image using a least squares regression
- Dark set-bright set (Hall et al., 1991), using an average value from a dark
and bright set for the actual minimum and maximum values in the scene

- Pseudoinvariant features (Schott et al., 1988)
- A controlled regression using a no-change pixel set (Yuan and Elvidge, 1993 and Elvidge et al., 1995).

Yuan and Elvidge’s visual inspection shows that the no-change set method gives the best results, and that the minimum-maximum, mean-standard deviation and pseudoinvariant feature methods yield poor matches to the reference image. Using the mean square error as a statistical measure of goodness of fit, Yuan and Evlidge (1996) ranked the methods with the "best" at the top of the list:

- No change pixel set
- Dark/bright set
- Simple regression
- Haze correction
- Mean-standard deviation
- Minimum-maximum
- Pseudoinvariant features.

The researchers point out that the methods can be further evaluated with regard to their effectiveness in the presence of clouds and statistical outliers. This suggests that a given method’s rank may be different if these are present in the images studied.

Automated Radiometric Normalization

A radiometric normalization extension developed by Tom Van Niel for use in ArcView will be used for this study. It is based on Hall et al (1991) and is designed to ease the burden of standardizing large numbers of Landsat images. A summary description of the methods used in the extension is taken from the Help files accompanying the scripts:

The atmospheric correction extension is an extension to ArcView designed to accomplish a relative atmospheric correction on a multi-temporal set of Landsat
Multi-Spectral Scanner (MSS) and/or Thematic Mapper (TM) satellite imagery. The extension is designed to follow a three-step iterative process which includes conversion of "raw" Digital Number (DN) ERDAS Imagine images to at-satellite (also known as exoatmospheric) reflectance or radiance, calculation of the Soil Brightness Index (SBI) and Green Vegetation Index (GVI) using the "Tasseled Cap" transformation, and relative atmospheric correction using Pseudo Invariant Features (PIFs). The extension also includes programs that allow the user to set environment variables for choosing the number of Pseudo Invariant Features (PIFs) and calculation of Vegetation Indices (VIs).

**THESIS OBJECTIVES**

1) Develop a validation protocol for the automated relative radiometric standardization.

2) Develop a protocol to standardize archival Landsat Multispectral Scanner imagery to Landsat Thematic Mapper for use in change detection studies which require scenes from more than one sensor.

**HYPOTHESES**

1) $H_0$: The automated correction does not reduce radiometric differences between input and reference images.

$H_A$: The automated correction does reduce radiometric differences between input and reference images.

2) $H_0$: Bandwise regression cannot be used to adequately standardize Multispectral Scanner and Thematic Mapper imagery for comparison in a change detection study which utilizes data from both sensors.

$H_A$: Regression is an effective method for standardizing MSS data to TM.
DATA AND STUDY AREA

The data for this project consist of a 25-year biannual set of Landsat MSS and TM images over the Provo, UT area, covering the wet and dry seasons of each year. The images have been clipped to a quadrangle which includes Utah Lake and a portion of the Great Salt Lake as well as a section of the Wasatch Front. The land within the clip is spectrally diverse and contains an array of surface features from bare rock and urban areas through grass and shrub lands to needle leaf forests and irrigated farm land. Some images contain snow or cloud cover as well.

METHODS

This section summarizes the steps necessary to complete the objectives of this project, from processing the images to validating the normalization procedure and standardizing across sensors.

Image Pre-processing

The images are first georectified to a single scene which has been georectified and terrain corrected with digital elevation models. All images are then clipped to the study area. Lastly these clips are radiometrically standardized to a master image using the automated radiometric normalization process described earlier.

Selecting a Reference Image

The benefits of image-to-image radiometric normalization are optimized when the reference scene has a minimum of clouds, snow and haze. All of the TM clips were visually inspected for clarity and a list was made of potential reference images. Potential
MSS reference images are selected by matching dates from the TM reference list and available data. A same-date pair will be used to standardize the entire Camp Williams time series.

**Crossing the MSS-TM barrier**

Data from the MSS and TM sensors are not directly comparable and these differences must be addressed if images from these two sensors are to be compared in a change detection study. To evaluate and model the differences between Landsat TM and MSS data, I will acquire temporally coincident imagery of each and develop a transfer function to normalize MSS to TM imagery.

**Validating the Radiometric Normalization Procedure**

Output images from the program will be compared to both the input and reference images to verify that the program reduces differences between the reference image and the rest of the data set.

**EXPECTED RESULTS**

I expect that the program will have difficulty finding common bright points between a reference/input pair when one scene contains clouds or snow. Even so, I expect the program will reduce differences between scenes, improving their comparability in a change detection framework.
REFERENCES


