A STUDY ON INTER-RELATIONSHIP OF VEGETATION INDICES USING IKONOS AND LANDSAT-7 ETM+ IMAGERY

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ABSTRACT

There is an increasing need to use data from different sensors in order to maximize the chances of obtaining a cloud-free image and to meet timely requirements for information. However, the use of data from multiple sensor systems is depending on comprehensive relationships between sensors of different types. Indeed, a study of inter-sensor relationships is well advanced in the effective use of remotely sensed data from multiple sensors.
This paper was concerned with relationships between sensors of different types for vegetation indices (VI). The study was conducted using IKONOS and Landsat-7 ETM+ images. IKONOS and Landsat-7 ETM+ image of the same or about the same dates were acquired. The Landsat-7 ETM+ images were resampled in order to make them coincide with the pixel sizes of IKONOS. Inter-relationships of vegetation indices between images were performed using at-satellite reflectance obtained by converting image digital number (DN). All images were applied to topographic normalization method in order to reduce topographic effect in digital imagery. Also, Inter-sensor model equations between two sensors were developed and applied to other study region.
In the result, the relational equations can be used to compute or interpret VI of one sensor using the VI of another sensor.

KEY WORDS: Inter-relationship, Vegetation indices, IKONOS, Landsat-7 ETM+, sensor

1. INTRODUCTION

There is an increasing need to use data from different sensors in order to maximize the chances of obtaining a cloud-free image and to meet timely requirements for information. However, the use of data from multiple sensor systems is depending on comprehensive relationships between sensors of different types. Indeed, a study of inter-sensor relationships is well advanced in the effective use of remotely sensed data from multiple sensors.

Recent studies have shown that the image products from Landsat 5 and 7 data indicate a high degree of similarity, which implies that monitoring activities initiated using Landsat 5 data, can be continued with a minimal amount of caution using Landsat-7 data (Vogelmann et al. 2001). Relationships between ecological variables and spectral derived indices using Landsat TM and ETM+ data were reported by Nouvellon et al. (2001). These relationships will differ when different sensors such as IKONOS are used and related to Landsat-7 ETM+ as a result of the inherent differences in the characteristics of sensors. Recently, a research of Inter-relationships between IKONOS and Landsat-7 ETM+ using NDVI (Normalized Difference Vegetation Index) for three ecoregions located in African rainforest and savannas was reported by Thenkabail. (2003).

Regarding the above background, the main goal of this paper was to develop inter-sensor model equation between IKONOS and Landsat-7 ETM+ and evaluate to developed model equation.

2. NDVI (NORMALIZED DIFFERENCE VEGETATION INDEX)

By 1973, Rouse et al. proposed the NDVI as a simple algorithm to process remote sensing data and locate the distribution of vegetation. NDVI was one amongst many attempts to simply and quickly identify vegetated areas, but it was the most well-known and used index to detect live green plant canopies in multispectral remote sensing data. (Jensen, J. R., 1996)

NDVI calculated using equation 1.

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (1)$$

Where Red, NIR = the spectral reflectance measurements acquired in the red and near-infrared regions, respectively.

The difference in reflectances was divided by the sum of the two reflectances. These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually; hence they take on values between 0.0 and 1.0. By design, the NDVI itself thus varies between -1.0 and +1.0.

3. EXPERIMENTAL RESULTS

3.1 IKONOS and Landsat-7 ETM+ datasets

The study was conducted using IKONOS and Landsat-7 ETM+ images of two distinct regions of the GANGWON and the DAEJEON, KOREA (Table 1 and Figure 1).

Table 1. Study areas and acquisition dates of images

Sensor / Region	Acquisition date	Solar elevation (degree)	Azimuth angle (degree)
IKONOS GANGWON, KOREA	05/08/2000	61.94	129.4
Landsat-7 ETM+ GANGWON, KOREA	05/08/2000	62.1	130.9
IKONOS DAEJEON, KOREA	03/11/2002	45.8	153.5
Landsat-7 ETM+ DAEJEON, KOREA	03/09/2002	43.4	144.0

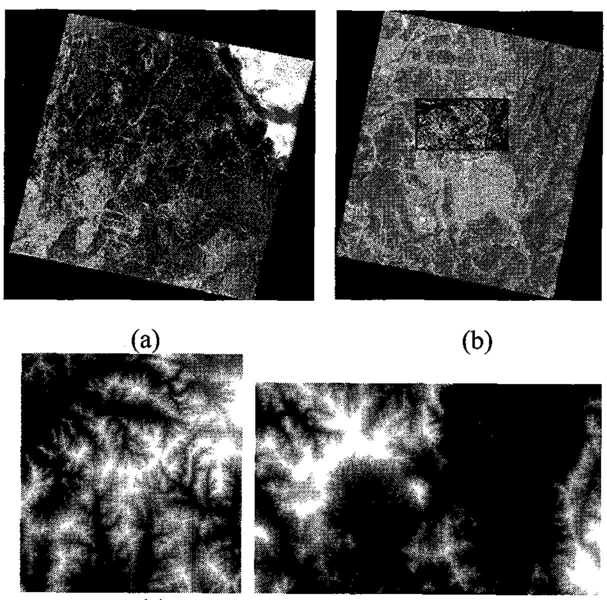


Figure 1. IKONOS (in rectangle), Landsat-7 ETM+ images, and DEM (c, d) ((a)GANGWON, (b)DAEJEON)

For each region, one IKONOS and one Landsat-7 ETM+ image of the same or about the same dates were acquired (Table 1). This will facilitate a direct comparison in spectral relationship between two sensors that have many characteristic differences. Sample study sub areas of IKONOS and Landsat-7 ETM+ images of each region are presented with rectangle (Figure 1).

The Landsat-7 ETM+ images were resampled from 30 m spatial resolution to 4 meter in order to make them coincide with the pixel sizes of IKONOS. In each study area, all images were rectified to a method of ortho correction and geometric correction. Relationships between images were performed using at-satellite reflectance obtained by converting image digital number (DN) to the temporally comparable surface reflectance factor (Moran et al., 2001).

3.1.1 Topographic normalization

Digital imagery from mountainous regions often contains a radiometric distortion known as topographic effect. One way to reduce topographic effect in digital imagery is by applying transformations such as the Lambertian or Non-Lambertian reflectance models. These models normalize the imagery, making it appear if it were a flat surface instead of topographic data.

When using the Topographic Normalization model, must be need the following information:

- Solar elevation and azimuth of sensor at time of image acquisition
- DEM file

Solar elevation and azimuth of sensor at time of image acquisition showed that Table 1. The Topographic Normalization model was derived from algorithm (2) (Hodgson et al., 1994).

$$BV_{normal\lambda} = \frac{BV_{observed\lambda}\cos e}{k(\cos i)(\cos e)} \qquad (2)$$

Where $BV_{normal\lambda}$ = normalized brightness values

$BV_{observed\lambda}$ = observed brightness values

$\cos i$ = cosine of the incidence angle

$\cos e$ = cosine of the exitance angle, or slope angle

k = the empirically derived Minnaert constant (if unknown, these may be set to 1.0 and the model becomes Lambertian)

3.1.2 Radiance and Reflectance

Digital numbers were converted to radiance and at-satellite reflectance (Price, 1987, Markam and Barker, 1987) using equations 3, 4, and 5.

$$\text{IKONOS Radiance (mW/cm2 - sr)} = \text{DN / Calibration coefficient} \qquad (3)$$

where DN = digital number

Calibration coefficients (Table 2)

Table 2. Calibration coefficients for IKONOS bands

IKONOS Radiometric Calibration Coefficients for 11 bit products [DN*cm^2*sr/mW]				
Production Date	Blue	Green	Red	NIR
pre 2/22/01	633	649	840	746
post 2/22/01	728	727	949	843

http://www.geoeye.com/

Solar flux or irradiance (mWcm-2) for IKONOS was: band 1=9.98, band 2= 12.7, band 3= 9, and band 4=9.15.

$$\text{Landsat 7 ETM + Radiance (Wm -2 } \mu m \text{ -1)} = \text{gain} * \text{DN} + \text{offset} \quad (4)$$

This is also expressed as (Price, 1987, Markham and Barker, 1987):

$$Radiance = \left(\frac{LMAX - LMIN}{QCALMAX - QCALMIN}\right) \times (QCAL - QCALMIN) + LMIN \quad (4)$$

Where QCALMIN = 1, QCALMAX= 255,
QCAL = digital number.
Lmax values were (Wm-2sr-1µ m-1):
Landsat-7 ETM+1=191.6,
Landsat-7 ETM+2=196.5,
Landsat-7 ETM+3=151.9,
Landsat-7 ETM+4=241.1,
Landsat-7 ETM+5=31.06,
Landsat-7 ETM+7=10.8.
Lmin values were (Wm-2 sr-1µ m-1):
Landsat-7 ETM+1= -6.2,
Landsat-7 ETM+2= -6.4,
Landsat-7 ETM+3= -5,
Landsat-7 ETM+4= -5.1,
Landsat-7 ETM+5= -1,
Landsat-7 ETM+7= -0.35.
Solar flux (Wm-2µ m-1) values were:
Landsat-7 ETM+1=1970,
Landsat-7 ETM+2=1843,
Landsat-7 ETM+3=1555,
Landsat-7 ETM+4=1047,
Landsat-7 ETM+5=227.1,
Landsat-7 ETM+7= 80.53.

Radiance to Reflectance

$$\rho_p = \frac{\pi \times L_\lambda \times d^2}{ESUN_\lambda \times \cos\theta_s} \quad (5)$$

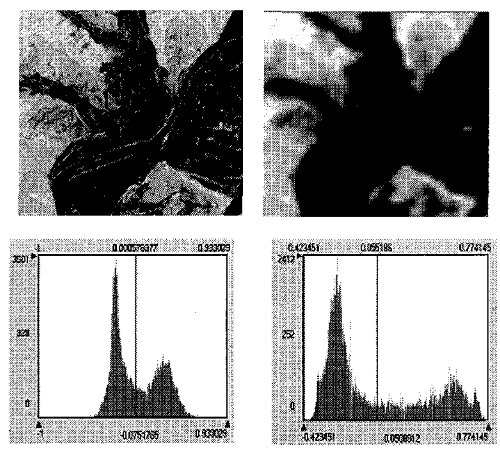
Where ρ_p = at-satellite reflectance (unitless),
L_λ = radiance mW cm-2 sr-1 (for IKONOS)
or W m-2 µ m-1 (for Landsat-7 ETM+),
d = earth to sun distance in astronomic units,
ESUN = Mean solar irradiances or solar flux (mW cm-2) for IKONOS or (W m-2 µ m-1) for Landsat-7 ETM+.

3.1.3 Inter-sensor relationships between IKONOS and Landsat-7 ETM+

The regression models relating the IKONOS NDVI and the Landsat-7 ETM+ NDVI were developed by using the resampled pixel sizes of Landsat-7 ETM+ (from 30 meter to 4 meter) and IKONOS. These models provided the following relationships:

$$\text{IKONOS NDVI} = 0.6799 * \text{Landsat-7 ETM+} - 0.0364 \quad [R^2 = 0.78] \quad (6)$$

Model for GANGWON region (both NDVI of Landsat-7 ETM+ and IKONOS in 4 meter; Figure 2, Figure 3)



(a) (b)
Figure 2. NDVI of GANGWON region ((a)IKONS, (b)Landsat-7 ETM+)

The above relationships were based on using NDVI derived from apparent reflectance data.

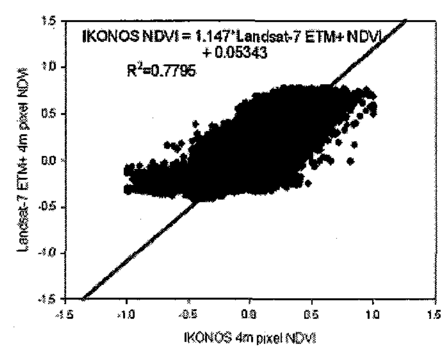
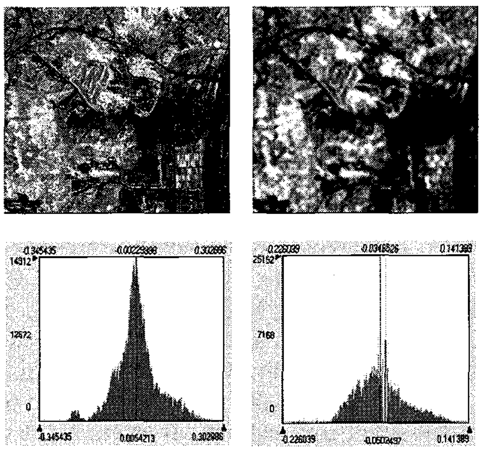


Figure 3. Inter-relationship of NDVI

3.1.4 Relationships evaluations

Actual IKONOS NDVI was computed for independent test areas of DAEJEON region. Predicted IKONOS NDVI was computed using Landsat-7 ETM+ for the same test areas based on the model equations 6 reported above. The 1:1 regression line shows a high degree of reliability (an R^2 value of 0.72) in predicting IKONOS NDVI based on the knowledge of Landsat-7 ETM+ NDVI. (Figure 5)



(a) (b)

Figure 4. NDVI ((a) Actual IKONOS, (b)Predicting IKONS)

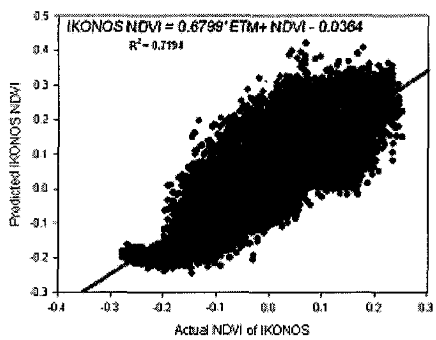


Figure 5. Inter-relationship (Predicted IKONOS NDVI and Actual Landsat-7 ETM+ NDVI)

The difficulty in predicting occurs with overall NDVI. This is mainly a result of the background reflectance and pixel size. The IKONOS NDVI is relatively very sensitive to background effects due to small pixel size compared to Landsat-7 ETM+ NDVI. The Landsat-7 ETM+ pixel often has multiple materials within a pixel, whereas IKONOS has far greater likelihood of data from a homogeneous pixel. This characteristic difference in sensitivity of the two sensors was led to above result.

4. CONCLUSION

The study helped establish relationships between IKONOS NDVI and Landsat-7 ETM+ NDVI by using data from a wide range of land use and land cover classes from the distinct regions. The model equations developed can be used to compute or interpret NDVI of one sensor (e.g., IKONOS) using the NDVI of another sensor (e.g., Landsat-7 ETM+) and vice versa. The recommended model equations are:

IKONOS NDVI = 0.6799 * Landsat-7 ETM+ - 0.0364

Well-understood inter-sensor relationships are necessary for utilizing satellite sensor data from multiple systems over time periods of decades.

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