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Calibration of ASTER and ETM+ Imagery Using Empirical Line Method—A Case Study of North-East of Hajjah, Yemen

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Abstract  This study is aimed at using the Empirical Line Method (ELM) to eliminate atmospheric effects with respect to visible and near infrared bands of advanced spaceborne thermal emission and reflection radiometer (ASTER) and enhanced thematic mapper plus (ETM+) data. Two targets (Amran limestone as light target and quartz-biotite-sericite-graphite schists as dark target), which were widely exposed and easy to identify in the imagery were selected. The accuracy of the atmospheric correction method was evaluated from three targets (vegetation cover, Amran limestone and Akbra shale) of the surface reflectance. Analytical spectral devices (ASD) FieldSpec3 was used to measure the spectra of target samples. ETM+ data were less influenced by the atmospheric effect when compared to ASTER data. Normalized differences vegetation indices (NDVI) displayed good results with reflectance data when compared with digital number (DN) data because it is highly sensitive to ground truth reflectance (GTR). Most of the differences observed before and after calibration of satellite images (ASTER and ETM+) were absorbed in the SWIR region.

Keywords  ELM; ASTER; ETM+; GTR; FieldSpec3

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Introduction

The study area is located in the northeast of Hajjah City, between longitudes 43° 36' 47" to 43° 40' 24" and latitudes 15° 42' 18" to 15° 50' 09". Generally, the relief of the area is mountainous, with moderate to steep slopes and sharp ridges (Fig.1). Distortions and noises contained in satellite images become serious impediments for quantitative analysis, so that remote sensing imagery generally requires correction for systematic defects or undesirable sensor characteristics before performing reliable data analysis[1]. DN of satellite images cannot be assumed to represent actual surface conditions because of various reasons, such as variable atmospheric attenuation, illumination geometry and sensor characteristics. Therefore, the quantitative utility of remote sensing data was maximized by calibrating it to a surface reflectance factor[2]. Atmospheric absorption involves reducing the brightness value of pixels in the near and middle infrared region (0.7-2.4 μm), which results from constituents such as molecular gases, CO₂, O₂, N₂ and
other nitrogen compounds and water vapor that are much smaller than the radiation wavelength \[3\].

Atmospheric correction is necessary for preprocessing technique in three cases. First, we may need to compute a ratio of the values in two bands of a multispectral image. Second, a researcher may wish to relate upwelling radiance from a surface to some property of that surface in terms of a physically based model. In the third case, the results or ground measurements made earlier (time 1) are required to be compared with results obtained later \[3\]. Band ratio (e.g., NDVI) is an example of the need for atmospheric correction \[4, 5\].

Radiance data of satellite images are influenced by the sun angle variations (solar irradiation spectrum) and atmospheric effects, which include absorption (most notably by H\(_2\)O, O\(_2\), and SO\(_2\)) and scattering particles and gases \[6\]. Removing these disturbances (effects) involves the conversion of the data from radiance to GTR and it also helps to remove the detector striping. Some methods of atmospheric correction also improve the spatial definition of objects and edges as they include correction for adjacency effects.

1 Empirical line method (ELM)

The ELM is an atmospheric correction technique that provides as an alternative to radioactive transfer modeling approach \[7\]. It is a common and effective way of correcting multispectral data from raw DNs, or radiance to reflectance factors \[2, 8, 9\]. It presumes that a linear relationship exists between image DNs and ground measurement reflectance for surfaces with a range of contrasting albedo (Fig. 2).

![Fig. 1 Location and physiographical map of the study area](image)

![Fig. 2 Empirical line method showing a linear relationship exists between image DNs and ground measurement reflectance for surfaces](image)

This linear relationship is used to calculate gains and offsets that convert DNs to reflectance factor \[2\]. Although this method is effective, there are limitations like accessing suitable homogeneous calibration sites. ELM also assumes that the effects of the atmosphere are uniform across the image \[8\]. This method requires a prior knowledge of the spectral characteristics of each target. Smith and Milton \[8\] emphasized that the ELM allows the calibration of remotely sensed data to reflectance with errors which are of only a small percentage. Karpouzli and Malthus \[7\] used the ELM for atmospheric correction of an IKONOS image. They showed that the ELM can be applied to correct such imagery to get accurate results.

The ELM method is also very sensitive to topographic variations when a large quantity of error getting introduced in areas having only moderate relief \[10\]. It is based on the following simplified equation \[5, 8, 11\]:

\[
R = s(L, \alpha)
\]

where \(R\) is the surface reflectance, \(L\) is the radiance recorded by the sensor, and \(\alpha\) is the slope of the line.
where $DN_b$ is the digital output value for a pixel in band $b$, $\rho(\lambda)$ is the scaled surface of the surface materials within that remote sensor Instrument Field of View (IFOV) at the wavelength $\lambda$ of band $b$, $A_b$ is a multiplicative term that affects the DN (transmittance and instrumental factors), and $B_b$ is an additive term (primarily atmospheric path radiance and instrumental offset, i.e., dark current).

Field spectroscopy has been in use for the calibration of aircraft and satellite sensors since the 1970s [12], but it was during the last 10-20 years that ‘vicarious calibration’ has become widely adopted as a means to provide independent assurance of quality of remotely sensed data from space-borne sensors.

2 Materials

2.1 Advanced spaceborne thermal emission and reflection radiometer (ASTER) and enhanced thematic mapper plus (ETM+)

The ASTER Level 1B data (acquired on 09-12-2004) were supplied from the Earth Remote Sensing Data Analysis Center (ERSDAC), Japan in HDF format. ASTER data were exported to the image format by using ERDAS Imagine version 9.1 image processing software. ETM+ data (acquired on 12-02-2004) which is geocoded into a UTM projection (WGS 84 - Zone 38 North) covered the studied area by one scene Path 166/ Row 49.

2.2 Analytical spectral devices (ASD) fieldspec3

The ASD instrument manufactured by Analytical Spectral Devices records 2151 channels and has reflectance within the range 0.350 - 2.500 $\mu$m wavelength. The system is characterized by a resolution of 0.003 $\mu$m at 0.700 $\mu$m and 0.0001 $\mu$m at 1.400 and 2.100 $\mu$m with the spectral sampling intervals of 1.4 $\mu$m in the 0.350-1.050 $\mu$m wavelength range and 2 $\mu$m in the 1.000-2.500 $\mu$m wavelength. It can also perform 10 spectra per second in data collection for the entire 0.350-2.500 $\mu$m range. A halogen lamp was used as an indoor illumination source. The instrument was calibrated with a calibration panel by means of a white reference (Spectralon) before taking measurements.

3 Methodology

Two targets were selected to calibrate ASTER and ETM+ data: quartz-biotite-sericite-graphite schist as dark target, and Amran limestone as a light target. Both were selected because they appeared clearly in the images. These two targets were so selected that they covered the entire range of reflectance. The spectrum of each sample was taken three times by using the ASD FieldSpec3 instrument. The accuracy of the calibration was tested by Akbra shale, vegetation cover, and mran limestone because they were very clear in the images.

4 Results and discussions

The spectral reflectance features of Akbra shale, vegetation cover and Amran limestone with both original DN and GTR of ASTER data are shown in Fig. 3(a), 3(b). Vegetation cover displayed in bands 1, 2, 3, 4 and 5 with the same features as that in both DN and GTR. Band 6 displayed the reflectance with calibration data and the absorption with DN data. Vegetation cover in bands 7 and 8 displayed the same features but with little fluctuations. Band 9 displayed the absorption feature with calibrated data and the reflectance with DN data. Amran limestone and Akbra shale rocks displayed quite opposite features in band 1, they displayed the reflectance with DN data, while displaying the absorption with calibrated data. In bands 2 and 3 they displayed the same features. In band 4, Amran limestone displayed reflectance with DN data and absorption with calibrated data, while Akbra shale displayed the same features in the two types of data. In bands 5 and 6 Amran limestone and Akbra shale displayed opposite features with the data before and after calibration. In bands 7 and 8, they displayed the same features. Amran limestone displayed opposite features in band 9 while Akbra shale displayed the same features. Based on the above analyses it was confirmed that SWIR bands were more affected by the atmospheric effects relative to VNIR bands.

The reflectance features of vegetation cover from Akbra shale and Amran limestone with data before
Fig. 3  Spectral profile of ASTER data

and after calibration (DN and GTR) of ETM+ are shown in Fig. 4(a),4(b). Vegetation cover displayed the same features in all bands under DN and GTR (before and after calibration) data. Akbra shale displayed the same features in all bands except 7, which showed reflectance with data after calibration and absorption with data before calibration. Amran limestone displayed the same features in all bands with fluctuation in band 3, which shows high reflectance in DN data and low (nearly flat) with GTR data.

NDVI is one example of application of calibration to both ASTER and ETM+. The values of NDVI after calibration for ETM+ and ASTER range from −0.158 to 0.490 and −0.246 to 0.503, respectively (Fig. 5(a), 5(b)), while the values before calibration vary from −0.376 to 0.291 (ETM+) and −0.379 to 0.400 (ASTER) (Fig. 6(a),6(b)).

5 Conclusion

The ELM was applied to calibrate ASTER and ETM+ data with highly satisfactory results. Spatial resolutions of both ASTER and ETM+ data and widespread (exposing) targets assist in selecting the targets of calibration and testing targets. ETM+ data are less influenced by the atmospheric effect compared to ASTER data. Most of the differences observed before and after calibration of satellite images

Fig. 5  NDVI from ETM+ and ASTER imagery after calibration
(ASTER and ETM+) were absorbed in the SWIR region. NDVI ratio is highly sensitive to calibration and displayed good results with reflectance data when compared with DN data. Based on the above analyses it can be generally concluded that there was not much difference in the spectral reflectance features before and after calibration. It was also proved that the lower effect was due to the location of the area, which is a dry and sparsely covered by vegetation.

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