Combining Decision Trees with Angle Indices to Identify Mangrove Forest at Shenzhen Bay, China

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Abstract: Mangroves are woody plant communities in the intertidal zone of tropical and subtropical coasts that play an important role in these zones. The infrared wave band is one of the key bands in the remote sensing identification of mangrove forest, and ALI (advanced land imagery) has a large number of infrared bands. Two angle indices were proposed based on liquid water absorption at band 5p and band 5 of EO-1 ALI, denoted as $\beta_{1.25}$ and $\beta_{1.65}$ respectively. A decision tree method was adopted to identify mangrove forest using remote sensing techniques for $\beta_{1.25}-\beta_{1.65}$ and NDVI (normalized difference vegetation index) for EO-1 ALI imagery acquired at Shenzhen Bay. The results showed that the reflectance of mangrove forests at band 5p and band 5 was significantly lower than that of terrestrial vegetation due to the characteristics of coastal wetlands of mangrove forests. This resulted in a greater $\beta_{1.25}-\beta_{1.65}$ Value for mangrove forest than terrestrial vegetation. The decision tree method using $\beta_{1.25}-\beta_{1.65}$ and NDVI effectively identifies mangrove forest from other land cover categories. The misclassification and leakage rates were 4.29% and 5.11% respectively. ALI sensors with many infrared bands could play an important role in discriminating mangrove forest.

Key words: mangrove; EO-1 ALI data; angle index; decision tree; Shenzhen Bay

1 Introduction
Mangrove forest ecosystems play an important role in coastal zones, not only in the biogeochemical cycle, but also in the economic life of the region via aquaculture and fishing. Human development activities and global environmental changes have reduced mangrove forests across China. For example, mangrove forests have decreased from 4.2×10^5 ha in 1950 to 2.28×10^4 ha in 2001 (Liao et al., 2014). In order to strengthen the management and supervision of mangrove forest resources in China, it is necessary to use remote sensing technology to document their temporal and spatial distribution.

Remote sensing identification and extraction methods for mangrove forests mainly include Supervised classification (Jensen et al., 1991; Rasolofoharinaro et al., 1998; Li et al., 2014), Unsupervised Classification (Li et al., 2014; Ferreira et al., 2009; Lee et al., 2009), Expert Classification (Li et al., 2006; Zhang, 2011), band ratios or a combination of vegetation index method (Chaudhury et al., 1990; Green et al., 1998), “3S” comprehensive method (Aschbacher et al., 1995; Long et al., 1994; Li et al., 2003), visual interpretation (Prasad et al., 2009; Seto et al., 2007), and object-oriented methods (Wang et al., 2004; Myint et al., 2008; Conchedda et al., 2008). In the classification, the original reflection characteristics, normalized difference vegetation index (NDVI) (Jensen et al., 1991), TM-TM7)/(TM5+TM7) (Chaudhury et al., 1990), TM5/TM4 (Green et al., 1998), TM5/TM4 (Green et al., 1998) and temperature-humidity index (Zhang et al., 2012) are usually used to distinguish...
mangrove and non-mangrove forests. Some studies using auxiliary geoscience data (tidal level, elevation and coasts) to improve mangrove recognition accuracy (Zhang et al., 2013; Liu et al., 2005; Liu et al., 2008). Images used for the present study include Landsat MSS (Giri et al., 2007), Landsat TM (ETM) (Giri et al., 2007; Andriamparany et al., 2010), SPOT (Blasco et al., 2001; Phan et al., 2007) and ASTER (Vaiphasa et al., 2006). EO-1 launched on 21 November 2000, has obtained high quality data and will continue until 2016 (Middleton et al., 2013). ALI (Advanced Land imagery) sensor was embarked on the EO-1 in band set device in addition to the operating band of the sensor, increasing the blue band (band 1p) and two near infrared band (near infrared band 4p and band 5p). Only a few studies thus far have utilized ALI data to monitor mangroves.

Mangroves are typical coastal wetlands. Infrared is one of the key bands used in the remote sensing identification of mangrove forest, and ALI has a large number of infrared bands. In order to evaluate the ability of ALI infrared band in mangrove remote sensing recognition, we used EO-1 ALI image data from Futian Mangrove Reserve in Shenzhen and Mai Po Nature Reserve mangroves in Hong Kong to construct a spectral index through the full use of its unique infrared characteristics. We applied the decision tree approach to test mangrove remote sensing recognition.

2 Materials and methods

2.1 Study area

Futian Mangrove Nature Reserve in Shenzhen and Mai Po Marshes Natural Reserve in Hong Kong were selected in this study. They are respectively located in the northwestern and southern sections of the Shenzhen River Estuary, which is a famous wetland ecosystem. The Mangrove Nature Reserve along the coastline forms a zonal shape up to 11 km, whose bandwidth is 20–400 m. Bordering Futian Mangrove Reserve in Shenzhen, Mai Po Nature Reserve in Hong Kong is one is listed as a wetland of international importance within China. Acanthus ilicifolius, Aegiceras corniculatum, Avicennia marina, Bruguiera gymnorrhiza, Exocaricia agallocha and Kandelia candel are the major mangrove plant species here. The study area has a subtropical monsoon climate, and the annual average temperature is 22.4°C and annual rainfall is 1950.5 mm (Lin et al., 2002). Land cover types include terrestrial natural forest, mangrove forest, artificial facilities, beaches, bare soil and water.

2.2 Data sources

Data included EO-1 ALI image data, 1:50000 topographic map, and high spatial resolution image data from Google Earth on 17 December 2005 and 10 December 2007 as validation data (note: Google Earth in 2006 without high spatial resolution images). EO-1 satellite contains three remote sensing devices (hyper spectral imaging spectrometer (Hyperion), advanced land imagery and atmospheric corrector). We used ALI imagery data from the Computer Network Information Center (Chinese Academy of Sciences) and geospatial data cloud (http://www.gscloud.cn). Images were from the Advanced Land Imager on NASA’s EO-1 satellite and taken on 21 December 2006, track number for P122 / R44 at a spatial resolution of 30 m.

2.3 Methods

2.3.1 Data preprocessing

Data preprocessing includes radiometric and geometric correction of ALI imagery. The radiometric correction includes the inversion of radiometric calibration whose calibration coefficient comes from the image metadata file and the surface reflectance was obtained using the FLAASH module of ENVI 4.8. The atmospheric model is set to be tropical; aerosol is set to urban. Geometric precision correction is processed using 1:50000 topographic maps as reference datasets, and using UTM projections as images.

2.3.2 Taxonomic characters

The band 5p, band 5 and band 7 of the ALI sensor can effectively reflect the pixel value in the surface features of moisture information. The mangrove spectral signal not only contains forest vegetation information, but also background water information. In order to effectively identify mangrove forests, we built an Angle Index of band 5p and band 5 (Angle Index, AI: the unit is radian, which are $\beta_{1.25}$ and $\beta_{1.65}$ in Table 1). The formulas are calculated as follows:

$$\beta_{1.25} = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right)$$  \hspace{1cm} (1)

$$\beta_{1.65} = \cos^{-1}\left(\frac{b^2 + d^2 - e^2}{2bd}\right)$$  \hspace{1cm} (2)

where $a$, $b$, $c$, $d$ and $e$ stand for the spectral reflectance curve respectively, constructing triangles (Fig. 1).

We further constructed taxonomic features $\beta_{1.25} - \beta_{1.65}$ and built the decision-tree model with NDVI and $\beta_{1.25} - \beta_{1.65}$ to extract mangroves.

![Fig. 1 Reflectance spectral curves extracted from ALI imagery of typical land covers types in the study area and diagrammatic sketch of Angle Index](image-url)
2.3.3 Decision-tree method
There are two decision rules for using decision tree classification methods to extract mangrove information:

Rule 1: $\text{NDVI} \leq 0.5$, this decision rule divides land-covers into vegetation (including mangroves and terrestrial vegetation) and non-vegetation (including water body, artificial buildings, beaches and bare soil).

Rule 2: $\beta_{1,25} \text{NDVI} - \beta_{0,65} \geq 0.01$, this rule distinguishes mangroves from terrestrial vegetation in a wetland background. This satisfies this rule is mangrove forests, otherwise is terrestrial vegetation. The thresholds for NDVI and $\beta_{1,25} - \beta_{0,65}$ are determined by repeated analysis.

3 Results

3.1 Spectral characteristics of typical land-cover
In order to facilitate comparative studies in the spectrum characteristics of typical land-covers, based on typical field ground survey data and high spatial resolution of Google Earth imagery, we selected typical land-cover (mangroves, terrestrial forest, artificial building, water body, beach, bare soil), each of 50–100 typical pixels, extracted from ALI images within the study area using visual interpretation methods.

The spectral curves of terrestrial vegetation and mangrove forests show typical vegetation reflectance characteristics manifested as a ‘two valleys, a peak and a steep slope’ in the visible band. Near-infrared was presented as a highly reflective platform. Shortwave infrared band reflectance sharply decreased due to moisture absorption of the vegetation canopy.

Because of the growth of sea grass, the intertidal zone is at low tide in all imaging data; the spectral curve of beaches reflects vegetation characteristics.

Reflectivity in the visible light region was higher than the vegetation’s, while reflectivity in the infrared region was significantly lower than for vegetation. Compared with vegetation, the spectral characteristics of non-vegetation, such as artificial buildings, bare soil and water bodies have obvious differences. Therefore, NDVI and the spectral characteristics of the shortwave infrared region can clearly distinguish non-vegetation from vegetation.

At the same time, based on the pixel sample data selected from typical features, the spectral characteristics of the above-mentioned land-covers, such as NDVI, $\beta_{1,25}$, $\beta_{0,65}$ and $\beta_{1,25} - \beta_{0,65}$, were counted.

The NDVI value of terrestrial vegetation and mangrove forests were significantly higher than for other types (Fig. 1, Table 1). The NDVI value of the beach was slightly larger than for artificial buildings and bare soil, and the NDVI value for water bodies was minimal. Therefore, mangrove forests and terrestrial vegetation can be separated from other land-cover using NDVI.

Terrestrial vegetation’s $\beta_{1,25}$ value was the smallest. The $\beta_{1,25}$ value of mangroves and artificial buildings was intermediate, the $\beta_{0,65}$ value of water, tidal flats and bare soil was larger. The $\beta_{0,65}$ value of terrestrial vegetation and mangrove forests was minimal, the $\beta_{0,65}$ value of artificial buildings and beaches were mid-range. The $\beta_{0,65}$ value of water and bare soil was the maximum recorded.

For $\beta_{1,25} - \beta_{0,65}$, the largest was for mangrove forest (0.110); beaches (0.031) and water body (0.011) were mid-range, bare soil (–0.125), artificial construction (–0.148) and terrestrial vegetation (–0.172) were smaller. Therefore, this feature can separate mangroves from terrestrial vegetation. The reason for this is that the wetland background of mangroves makes the pixel reflectance of band 5p and band 5 significantly lower than for terrestrial vegetation.

3.2 Mangrove identification results and its accuracy evaluation
By building a decision-tree model, we conducted a recognition experiment for mangroves within the study area (Fig. 2). The map of the ALI image is a true color synthesis image in which the red area was mangrove (Fig. 2). With high resolution image data from Google Earth on 17 December 2005 and 10 December 2007, we selected precision validation samples and randomly extracted 1621 pixels from the image as validation samples, including mangroves (235), terrestrial vegetation (473) and non-vegetation (913) (including water body, artificial building, bare soil and beach). The recognition accuracy of mangroves was as follows: misclassification rate was 4.29% and the leakage rate was 5.11%.

Missing mangrove pixels were mainly located in the intertidal beach where the mangrove often was submerged by seawater when the super high tide took place, and these mangroves were less humid than the bund in the intertidal zone. Therefore the $\beta_{1,25} - \beta_{0,65}$ of these mangroves was relatively small and easy to miss. Mixed pixels of terrestrial vegetation and water bodies were mainly misclassified as mangroves. Because these pixels contained water and vegetation information and their spectrums were very similar to mangroves, they were wrongly classified as mangroves.
Table 1  Statistical values of spectral features of typical land cover

<table>
<thead>
<tr>
<th></th>
<th>Statistics</th>
<th>Terrestrial vegetation</th>
<th>Water body</th>
<th>Mangrove</th>
<th>Artificial building</th>
<th>Beach</th>
<th>Bare soil</th>
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</thead>
<tbody>
<tr>
<td>N\text{DVI}</td>
<td>Minimum</td>
<td>0.778</td>
<td>-0.435</td>
<td>0.676</td>
<td>0.038</td>
<td>0.217</td>
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<tr>
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<td>Maximum</td>
<td>0.849</td>
<td>-0.343</td>
<td>0.857</td>
<td>0.096</td>
<td>0.323</td>
<td>0.093</td>
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<td></td>
<td>Mean</td>
<td>0.827</td>
<td>-0.393</td>
<td>0.814</td>
<td>0.070</td>
<td>0.285</td>
<td>0.071</td>
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<td>Variance</td>
<td>0.012</td>
<td>0.018</td>
<td>0.036</td>
<td>0.010</td>
<td>0.029</td>
<td>0.011</td>
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<tr>
<td>(\beta_{1.25})</td>
<td>Minimum</td>
<td>2.552</td>
<td>3.119</td>
<td>2.827</td>
<td>2.722</td>
<td>3.040</td>
<td>2.948</td>
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<td>Maximum</td>
<td>2.758</td>
<td>3.141</td>
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<td>3.028</td>
<td>3.111</td>
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<tr>
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<td>Mean</td>
<td>2.618</td>
<td>3.136</td>
<td>2.898</td>
<td>2.913</td>
<td>3.078</td>
<td>3.009</td>
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<tr>
<td></td>
<td>Variance</td>
<td>0.039</td>
<td>0.004</td>
<td>0.033</td>
<td>0.073</td>
<td>0.017</td>
<td>0.027</td>
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<tr>
<td>(\beta_{0.65})</td>
<td>Minimum</td>
<td>2.735</td>
<td>3.115</td>
<td>2.763</td>
<td>2.995</td>
<td>3.031</td>
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<tr>
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<td>Maximum</td>
<td>2.862</td>
<td>3.137</td>
<td>2.958</td>
<td>3.097</td>
<td>3.058</td>
<td>3.141</td>
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<tr>
<td></td>
<td>Mean</td>
<td>2.790</td>
<td>3.125</td>
<td>2.829</td>
<td>3.060</td>
<td>3.047</td>
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<td>Variance</td>
<td>0.025</td>
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<td>0.007</td>
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<tr>
<td>(\beta_{1.25}-\beta_{0.65})</td>
<td>Minimum</td>
<td>-0.231</td>
<td>-0.017</td>
<td>0.011</td>
<td>-0.363</td>
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<tr>
<td></td>
<td>Maximum</td>
<td>-0.080</td>
<td>0.021</td>
<td>0.213</td>
<td>-0.017</td>
<td>0.056</td>
<td>-0.055</td>
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<tr>
<td></td>
<td>Mean</td>
<td>-0.172</td>
<td>0.011</td>
<td>0.110</td>
<td>-0.148</td>
<td>0.031</td>
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<tr>
<td></td>
<td>Variance</td>
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<td>0.006</td>
<td>0.061</td>
<td>0.072</td>
<td>0.013</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Note: \(\beta_{1.25}\) and \(\beta_{0.65}\) indicate the angle index of band 5p and band 5.

4 Conclusions

Pixel reflectance of mangrove forests is significantly lower than terrestrial vegetation at band 5p and band 5 due to coastal wetlands features. \(\beta_{1.25}-\beta_{0.65}\) can be used to distinguish mangrove forests from terrestrial vegetation. Based on ALI imagery, the decision tree method with \(\beta_{1.25}-\beta_{0.65}\) and NDVI increases the accuracy of identification of mangrove forests.

The infrared band is one of the key bands for the remote sensing recognition of wetland vegetation. Numerous infrared bands make ALI remote sensor play an important role in the remote sensing monitoring of wetland vegetation. Based on ALI imagery, the decision tree method with \(\beta_{1.25}-\beta_{0.65}\) and NDVI increases the accuracy of identification of mangrove forests.


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