Mapping Mangrove Species with High Resolution Optical and Polarimetric SAR Satellite Data

Hongsheng Zhang and Hui Lin

Institute of Space and Earth Information Science,
The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong
Email: stevenzhang@cuhk.edu.hk

KEY WORDS: Mangrove species, Worldview-3, Radarsat-2, Mai Po

ABSTRACT: Mangrove forests are the most productive and important ecosystems which provide significant ecosystem services, such as carbon sequestration, flood mitigation, water quality protection and a wide range of habitats to support a rich variety of flora and fauna. Remote sensing provides a relatively easy and much less costly approach to monitor the dynamics of mangrove. However, remote sensing of mangrove is challenging due to the nature of mangrove and limitations of spectral and spatial resolutions of remote sensing data. Nowadays, advances in the high spatial and spectral resolutions of sensors now available to ecologists are making the direct remote sensing of certain aspects of biodiversity increasingly feasible. Very high spatial resolution optical data are more and more frequently used in the monitoring of mangrove forest. Additionally, the backscattering information for plants using active microwave remote sensing is also useful for identifying various mangrove species, since microwave is sensitive to the surface roughness and biophysical properties of mangrove forest. Nevertheless, the potential of synthetic aperture radar (SAR) is still under explored and discussion. Moreover, polarimetric SAR (PolSAR) data offer better capability for distinguishing different scattering mechanisms of ground targets, which will greatly help overcome the spectral confusion problems in optical data, and thus may provide complementary information for identifying various mangrove species. In this research, high spatial resolution satellite images from Worldview-3 and Radarsat-2 were employed to classify the mangrove species in the Mai Po wetland of Hong Kong. Spectral and textural features were extracted from the optical images and polarimetric features were extracted from the Radarsat-2 image. Support vector machine was applied to classify the mangrove species with the spectral and textural information from the optical image and polarimetric information from the PolSAR image. Subsequently, all these features were fused to identify the species with a supervised classification process. Statistical data of field survey from the Agriculture, Fisheries and Conservation Department of Hong Kong government was used to validate the results in this study. Experimental results indicated that 1) mangrove species classification with very high resolution satellite images was generally low (less than 80% of the overall accuracy) due to the highly spectral confusion between different mangrove species; 2) polarimetric features did not provide a generally positive result to the accuracy, while it was able to improve the accuracy of some species; 3) the combination of very high resolution optical and polarimetric SAR images is necessary to improve the accuracy of mangrove species mapping.

1. INTRODUCTION
Mangrove forests are the most productive and important ecosystem because of their ecological, biological and socioeconomic significance (Bahuguna, Nayak, and Roy 2008; Duke et al. 2007; Giri et al. 2011; Jia et al. 2014). However, mangrove forests have decreased dramatically during the past century due to various human activities such as urbanization, agriculture conversion and tourism (Alongi 2008; Duke et al. 2007; Giri et al. 2008). Monitoring the spatial distribution of mangrove forests is imperative to better understand the dynamics of mangrove forests such as succession, deforestation, stand density and health conditions, as well as to further understand the ecological services from mangrove forests (Duke et al. 2007; Giri et al. 2011; Jia et al. 2015; Kuenzer et al. 2011; Wang et al. 2004). Traditionally, field survey was the most common approach to collect and analyse the distribution and expansion of mangrove forests, while intensive field survey is often difficult as most mangrove forests are located in protected and inaccessible areas (Kuenzer et al. 2011). Therefore, remote sensing has increasingly become a unique and advantageous methodology to monitor mangrove forests from local to global scales (Giri et al. 2007; Kuenzer et al. 2011; Wang et al. 2004). Conventionally, a number of approaches have been proposed to monitor and analyse mangrove forests using remote sensing data from various data sources at different spatial, spectral and temporal resolutions. Regarding the remote sensing data sources, most previous studies can be grouped into two main categories, employing optical data (e.g. multispectral and hyperspectral data) and Synthetic Aperture Radar (SAR) data (single- and multi-polarimetric data) respectively. On the one hand, Wang et al. applied the object-based analysis method to high resolution satellite data (IKONOS and Quick) for mapping the mangrove species (Wang, Sousa, and Gong 2004; Wang et al. 2004). On the other hand, SAR satellite data have been increasingly used to study mangroves since active microwave is sensitive to the surface structure and biomass of mangrove forests. Filho et al. employed both Landsat and Radarsat-1 data to conduct a comprehensive classification over coastal forests in Brazilian Amazon Region (Souza and Paradella 2005). Nevertheless, the potential of SAR data and, in particular, in the manner of synergistic use with optical data, was underexplored in previous studies. This study aims to conduct a comprehensive comparison and evaluation of the potential of the recently launched very high resolution satellite, Worldview-3, and its combination with polarimetric Radarsat-2 SAR data for species discrimination of mangrove forests in Hong Kong.

2. STUDY AREA AND DATASET

The Mai Po Marshes Nature Reserve (MPMNR) was selected as the study site for mangrove species mapping in this study. MPMNR was located in the north-western part in New Territory, Hong Kong, and exactly bordering on Inner Deep Bay between Shenzhen and Hong Kong. There are two main groups of satellite remote sensing data. The latest high resolution optical data from Worldview-3 was employed as the optical data, while the dual polarimetric SAR data from Radarsat-2 was used as the SAR data. To preprocess the SAR image, basic radiometric correction and calibration processes are conducted. Speckles are reduced by filtering procedure. Considering the uncertainty of the speckle noises in SAR images, the Enhanced Lee filter was applied to filter the speckle noises comparatively (Lee et al. 1999; Lopes, Touzi, and Nezry 1990). Especially, there is an about two-month difference of the imaging dates between the Worldview-3 and Radarsat-2 data. However, as they fell into the same season, we assume that there is no significant change of the mangrove forests within this period. Finally, both the optical and SAR data are to be geocoded and co-registered using the Universal Transverse Mercator (UTM) projection (Zone 49N), and Datum World Geodetic System 1984 (WGS84). For field data collection, AFCD provided their historic field survey results in three different periods, 2004-2005, 2006 and 2007. In addition, our colleagues also conducted a field survey on 11
July 2013 by collecting mangrove species samples, with the support of global positioning system (GPS) and real time kinematic (RTK), with less than 1 m accuracy (Jia et al. 2014).

3. METHODS

3.1 Feature extraction
Image features were extracted from both Worldview-3 and Radarsat-2 data. Generally, three different groups of features can be extracted, including spectral features, textural features and polarimetric features. Spectral features are extracted from optical data by analysing the spectral reflectance or digital numbers for each band based on a single pixel. Spectral features are often based on some of the important bands which characterize the features of one land cover type, such as vegetation, water or soil. In this study, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) are employed as the spectral features for optical data (Goward et al. 1991; McFeeters 1996). Since there are two Near Infrared (NIR) bands in the eight-band Worldview-3 product, there are two different ways of calculating NDVI and NDWI. In order to compare the performance of these two different NIR bands, both of them were applied to the calculation and thus we have NDVI1, NDVI2, NDWI1 and NDWI2, corresponding to the standard band NIR1 (772-890 nm) and the additional band NIR2 (866-954 nm) in Worldview-3 data, respectively. Therefore, we get the following four equations to calculate the NDVI and NDWI values. Textural features are often beneficial towards land targets in high spatial resolution images as there are rich spatial details. Generally, there are numerous texture measurement approaches from the literatures, while the Grey Level Co-occurrence Matrix (GLCM) approach (Haralick, Shanmuga.K, and Dinstein 1973) has been widely employed and proved to be helpful in many study cases. Polarimetric SAR data can be represented in the form of a scattering matrix (S), which can be further transformed into a covariance matrix (C) or a coherency matrix (T). In this study, in order to comprehensively investigate the covariance matrix and coherency matrix for their potential in the mangrove species mapping, several parameters were calculated as the polarimetric features, including the elements of covariance matrix, the eigenvalues of coherency matrix, and alpha and entropy values from Cloude-Pottier decomposition (Cloude 2007; Cloude and Pottier 1997).

3.2 Mangrove species mapping
In this study, support vector machine (SVM) (Vapnik 1995; Weston and Watkins 1999) was employed as the classifier to identify various mangrove species. Since there are six mangrove species, namely, *Avicennia marina* (AM), *Acanthus ilicifolius* 1 (A11), *Acanthus ilicifolius* 2 (A12), *Kandelia obovata* 1 (KO1), *Kandelia obovata* 2 (KO2) and *Aegiceras corniculatum* (AC), and two other classes, water and mudflat, in this study, a multi-class SVM was needed. To apply a multi-class SVM from the original binary SVM version, the one-against-rest strategy was applied (Weston and Watkins 1999). Additionally, the Radial Basis Function (RBF) was used as the kernel function to map the input satellite data and extracted features from the original dimension to a higher dimension where various classes are linearly separable. The Gamma (G) parameter in the RBF and the penalty (C) parameter were optimized using a cross-validation procedure to find the optimal classification results.

4. RESULTS AND DISCUSSION
Mangrove species in the MPMNR region were successfully classified with the extracted features from Worldview-3 and Radarsat-2 data. Figure 1 illustrates the classification results, which indicate several major points: 1) water, mudflat and mangrove forests were well separated, which mainly depend on the features from the optical features; 2) six mangrove species were classified over the study area, where AM, KO1 and KO2 are the major mangrove species in MPMNR; 3) textural features from GLCM introduced noticeable edge effects, which cause some misclassification of mangrove species (Figure 1f); 4) Kandelia species, including KO1 and KO2, is the dominant mangroves in MPMNR. They can be generally identified over the whole region from north-east to south-west part (Figure 1). AM species, majorly distributing on the middle part of Mai Po, was generally identified by both optical and SAR features, while it is noticeably confused with KO1 species. The GLCM textural features was able to add useful information for the discrimination (Figure 1f), while edge effects can be observed and cause some misclassification of AC species. Polarimetric SAR features generally provide better results in identifying AM species with less confusion with KO1 species. The combination of all optical and SAR features was also able to improve the classification of AM species. However, the edge effects introduced by the GLCM features were also transported into the final results.

![Figure 1 Mangrove species mapping using various features from Worldview-3 and Radarsat-2 data](image)

Using the reference data and the confusion matrix, a quantitative comparison among the results shown in Figure 1 can be obtained in Table 1. It can be observed that not all the features provided positive information to the original standard 4-band Worldview-3 data. The original 4-band Worldview-3 data obtained an overall accuracy of 60.34% and a Kappa coefficient of 0.5198. If the optical features were added individually, NDWI2 and GLCM features were able to increase the accuracy by about 1%. The best optical feature is the GLCM textural feature which was able to get an overall accuracy of 75.95% and a Kappa value of 0.7091. The increase of accuracy from GLCM feature is somehow supervising since we can see the edge effects from Figure 3 introduced by the textural features. Actually, even with the edge effects, the improvement for the AM species recognition was able to increase the accuracy from 60.34% to 75.95%. If we add the SAR data and polarimetric features individually to the standard 4-band Worldview-3 data, some improvement can also be observed from the accuracy assessment. It is supervising to find that the the alpha-H decomposition did not add positive information to the classification result by decreasing the accuracy by about 1%. However, if the features from both Worldview-3 and Radarsat-2 data were combined, the overall accuracy
was increased by about 16.63% (to 76.98%) and the Kappa value by about 0.2016 (to 0.7214), which is the best accuracy compared to the use of other features. Actually, this result is not supervising as the information added by optical data and SAR data are not overlay. Therefore, the combination of the two data sources would combine both the useful information to compensate each other, and thus to increase the final classification accuracy compared to using single optical or single SAR data.

Table 1 Comparative accuracy assessments with various bands and features

<table>
<thead>
<tr>
<th>Features</th>
<th>Overall accuracy</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>WV3 (4 bands)</td>
<td>60.34%</td>
<td>0.5198</td>
</tr>
<tr>
<td>NDVI1</td>
<td>59.31%</td>
<td>0.5059</td>
</tr>
<tr>
<td>NDVI2</td>
<td>58.62%</td>
<td>0.4973</td>
</tr>
<tr>
<td>NDWI1</td>
<td>59.31%</td>
<td>0.5061</td>
</tr>
<tr>
<td>NDWI2</td>
<td>60.00%</td>
<td>0.5141</td>
</tr>
<tr>
<td>GLCM</td>
<td>75.95%</td>
<td>0.7091</td>
</tr>
<tr>
<td>Alpha-H</td>
<td>58.28%</td>
<td>0.4923</td>
</tr>
<tr>
<td>All features</td>
<td>76.98%</td>
<td>0.7214</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This study investigated the potential of the latest satellite Worldview-3 with eight-band product and Radarsat-2 with dual-polarimetric SAR produce for mangrove species mapping. Both spectral and textural features were extracted from the optical data, while polarimetric features were extracted based on coherency matrix and covariance matrix from the polarimetric SAR data. Then support vector machine (SVM) was applied with optimized parameters and the extracted features from optical and SAR data to classify six mangrove species in the Mai Po Marshes Nature Reserve in Hong Kong. Experimental results that polarimetric SAR data were able to generally increase the mapping of mangrove species, while more insightful studies are needed to investigate a better strategy for combining optical and polarimetric SAR data for improving mangrove species mapping at high spatial resolution.

References


