DETECTING INVASIVE PLANTS USING HYPERSPECTRAL AND HIGH RESOLUTION SATELLITE IMAGES

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ABSTRACT:

The rapid spread of nonnative plant species have caused considerable negative impact to the biodiversity and ecosystems in Taiwan. To better understand the status and to support researchers and decision makers to develop strategies and remedies for this problem, it is necessary to obtain accurate spatial information and the progression about the invasions of foreign species into native ecocommunity. The availability of hyperspectral and high resolution satellite data provides researchers an opportunity to pursue more complex analysis and have a great potential to achieve better performance and results in an invasive plants investigation. High resolution images provide detail spatial information about the target areas but are often limited to single or few spectral bands. On the other hand, hyperspectral data consist of tens to hundreds of contiguous bands but lack of spatial details. Therefore, a combination of both types of data is likely to be an optimal approach to the mapping of alien plants. However, with the large data volume and high data dimensionality, the major challenge of using hyperspectral and high resolution data together is to extract useful information effectively and efficiently. This paper presents a work in progress of developing a systematic method to use hyperspectral and high resolution satellite images to identify an invasive plant (horse tamarind, *Leucaena Leucocephala*) that is spreading in an alarming rate in southern Taiwan. The developed method first locates "areas of interest" where target species is likely to populate most densely. Then a two-level analysis procedure is implemented using hyperspectral and high resolution satellite images to identify and map the distribution of target species. The first phase of the procedure is to analyze hyperspectral images with selected (helpful) features to obtain a preliminary result. The second phase is to isolate the areas where discrimination of target plant species is not satisfactory and to improve the accuracy of discrimination with the analysis of canopy structures in high resolution satellite images. Verification with ground truth samples indicates that the developed method of combining high resolution and hyperspectral images analysis is an effective and efficient approach to detect invasive plants in a large area.

1 INTRODUCTION

Being an island surrounded by oceans, Taiwan has a natural barrier to prevent foreign species from invading the local ecosystems. The botanic ecosystems and biodiversity in Taiwan has been in good preservation status for hundreds of years. However, in the past decades, intentionally or not, a considerable amount of alien species have been brought into local environment because of the need to prosper economic development and the increase of international travel and trading. According to a previous investigation (Lai, 1995), the number of known nonnative plant species had reached a record-high 4,500 species in 1995. The rapid spread of alien plant species, especially those with aggressively invasive capability, have caused considerable negative impact to the biodiversity and ecosystems in Taiwan. Among them, horse tamarind (*Leucaena Leucocephala*) is one of the most serious invasive plant species and have colonized a large portion of southern Taiwan, in particular, the Kenting National Park located in the Hen-Chun peninsula of southern Taiwan (Jiang & Xiu, 2000). In some of the areas inside the national park, this root-toxic tree has completely replaced original native tropical forests and become the only vegetation type (Liu & Chen, 2002).

Reducing the impacts to local ecosystems and biodiversity caused by alien species and employing restoration and other remedy actions has become a trend in conservation (Stein & Flack, 1996). To better understand the status and to support researchers and decision makers to develop strategies and remedies for this threatening problem, it is necessary to obtain accurate spatial information and the progression about the invasions of alien species into native ecocommunity. Unlike field-based investigations, remote sensing provides an timely and economical approach for discriminating invasive plant species from local botanic community, especially in a large-scale investigation. Until relatively recently, aerial photographs and multispectral satellite images are the primary sources of remote sensing applications to vegetation mapping and have attained mixed success (for example, Lins et al., 1996; McCormick, 1999). However, because these types of data can provide only limited spectral information, they may not be

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able to produce results with high quality and confidence, especially when dealing with detection and mapping tasks down to the species level (Chen et al., 2003).

Fortunately, the availability of hyperspectral and high resolution satellite data provides researchers an opportunity to pursue more complex analysis. Hyperspectral imagery consists of tens to hundreds of contiguous spectral bands therefore can provide more complete coverage of spectral information about targets. Previous studies have demonstrated the possibility to perform species-level vegetation classifications using hyperspectral data (Cochrance, 2000; Laba et al., 2003; Schmidt & Skidmore, 2003). However, currently available hyperspectral satellite data have a limited ground resolution. This may create difficulties in producing precise mappings of vegetation types. On the other hand, although limited to single or few spectral bands, high resolution images provide detail spatial information about the target areas. Therefore, a combination of both types of data is likely to be an optimal approach to the mapping of nonnative plants.

In consequence, this research undertakes an effort to develop a systematic method to identify an invasive plant (*Leucaena Leucocephala*) in the Kenting National Park and vicinity of southern Taiwan using hyperspectral images and high resolution satellite images. Verification with ground truth samples indicates that the developed method of combining high resolution and hyperspectral images is an effective and efficient approach to detect invasive plants in a large area.

2 METHODS AND MATERIALS

2.1 Analysis Procedure

The method developed in this study consists of several analysis phases. First, candidate areas of interest where target plant (*Leucaena Leucocephala*) is most likely to be spotted are selected from the study area. The selection is done using NDVI and other vegetation indexing schemes from multispectral images or sub-images generated from hyperspectral images. In other words, regions with low possibility of vegetation distribution are filtered out. This is a practical necessity to reduce the data volume for analysis and to avoid negative impacts stemming from uninterested land-cover types.

The second phase of analysis is to perform spectral analysis on hyperspectral images to identify *Leucaena Leucocephala* from vegetation covered areas. The process begins with extracting helpful spectral features from training data and field-collected spectra of the target plant. The purpose of this process is to collect spectral features that are most helpful in discriminating *Leucaena Leucocephala* from other vegetation types. Then, a parallelpiped classification is applied to the hyperspectral images according to the selected features. One thing to note is that some of the features may be difficult, if not impossible, to obtain from original data. Therefore, methods developed to identify subtle features in transformed spectral domains should be used to achieve better analysis performance. For example, the derivative spectral analysis (Tsai & Philpot, 1998; Tsai & Philpot, 2002) has been proved to be effective and efficient for this purpose. Also, in a previous study (Underwood et al., 2003) researchers concluded that Minimum Noise Fraction (MNF) analysis method can usually produce better classification results when identifying specific vegetation types with hyperspectral imagery. Accordingly, this research also applies MNF transformation before classification process.

The preliminary classification result is then quickly evaluated with known ground truth samples to identify regions with poor discrimination of target plant. In these spots, texture analysis of high resolution images will be used to further examine the canopy structures and other features in order to increase the accuracy of target mapping. As of the time this paper is being formatted, the computerized texture analysis for this purpose is still under development. Therefore, the analysis results of high resolution images shown in this paper were produced from interactive texture analysis by experienced human interpretors.

2.2 Study Area

As shown in Fig. 1, the study area of this research is the Kenting National Park and vicinity located in southern Taiwan. The park was established in 1984 for the purpose of preserving natural resources and ecosystems. It covers an area of more than 33,000 hectors of land (about 18,000 hectors) and ocean with diversified coastal zones, terrains, land-cover types and wildlife. The vegetation cover in this region consists of a rich and fertile variety of native and exotic species.

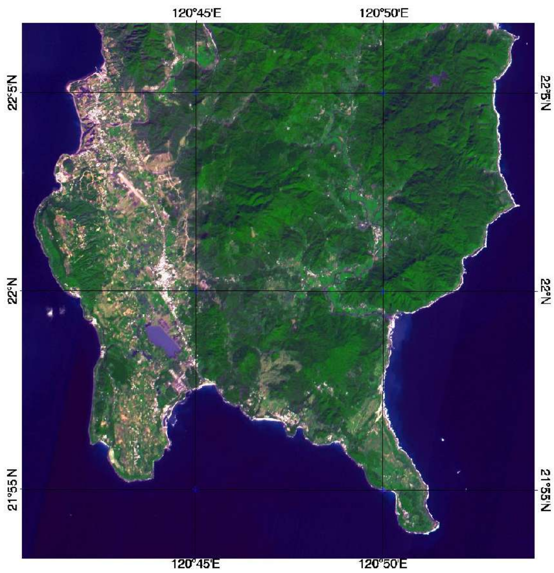

Figure 1. Study area (Kenting National Park and vicinity).

2.3 Primary Materials for Analysis

The primary data used for analysis in this study are three hyperspectral images acquired by NASA EO-1 Hyperion sensor and two sets of QuickBird high resolution images. Hyperion sensor has 220 unique channels covering from visible to short-wave infrared (357 – 2576 nm) of spectrum with a nominal ground resolution of 30m. Each Hyperion image delivered by NASA (via USGS) is Level 1 radiomeric corrected consisting of 242 bands but only 198 of them are calibrated. Because of an overlap between VNIR and SWIR focal planes of the sensor, there are only 196 unique channels in each image. In addition, some of the calibrated bands (mostly in water absorption regions) are excluded for analysis in this study because of low signal-to-noise ratio. Because the delivered images are not geometrically corrected, they were registered using ground control points before further analysis.

As mentioned earlier, the high resolution QuickBird images were used to fortify the discrimination of target plant in areas where spectral analysis of hyperspectral images did not produce satisfactory results. Two sets of QuickBird images have been used in this study to improve the analysis accuracy and more will be acquired if necessary as the project continues. Each set of the images consists of a 60cm resolution panchromatic image and a 2.4m spatial resolution multispectral (4 channels) image. Detail specifications about QuickBird products can be found at Digital Globe's web site and are not repeated here. The high resolution images were orthorectified with DEM and accurate maps of the study area.

In addition, this study also uses *in situ* spectra collected using a portable spectrometer (Ocean Optics USB2000) to help select spectral features that are helpful in separating *Leucaena Leucocephala* from other vegetation types. Also, several GIS data layers obtained from the park administration and other resources are used as reference data in this study. They are used in pre-processing the images (orthorectification and registration) as well as selecting training samples. Some of them are also used as ground truth to verify the analysis results.

3 RESULTS AND DISCUSSION

3.1 Analysis of Hyperspectral Images

After uncalibrated and low SNR bands were removed, the hyperspectral images were registered to the maps of the study area using at least 10 ground control points for each scene. The RMS errors of the registration were controlled to be less than half of a pixel. Before any spectral analysis was applied to the images, a set of training pixels were selected from the images. The selection process was helped by a vector layer generated from a previous field investigation. The GIS layer consists of polygons with 4 levels of population density of *Leucaena Leucocephala.* Four hundred training pixels were randomly selected from polygons that were labelled as having more than 50% of target plant. Part of the training samples are shown as green dots in Fig. 2.

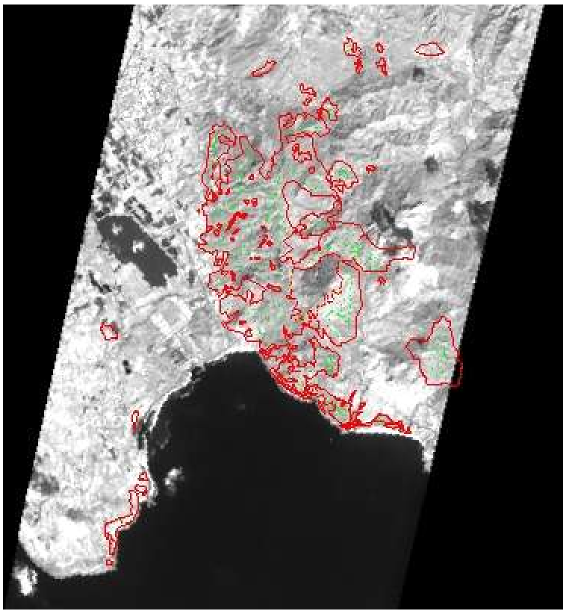

Figure 2. Training data (green dots).

A collection of "helpful" features that are capable of effectively discriminating target plant from surrounding vegetation clusters were extracted from the training data and field-collected spectra for subsequent analysis of the hyperspectral images.

As indicated earlier, the MNF operation is believed to be a better base for species-level discriminaion. Therefore, the images were transformed using built-in MNF algorithm. Fig. 3 and Fig. 4 demonstrate two of the MNF bands from one of the three Hyperion images. Then, sub-images of selected MNF bands were analyzed using parallel-pipe classifiers according to selected spectral features.

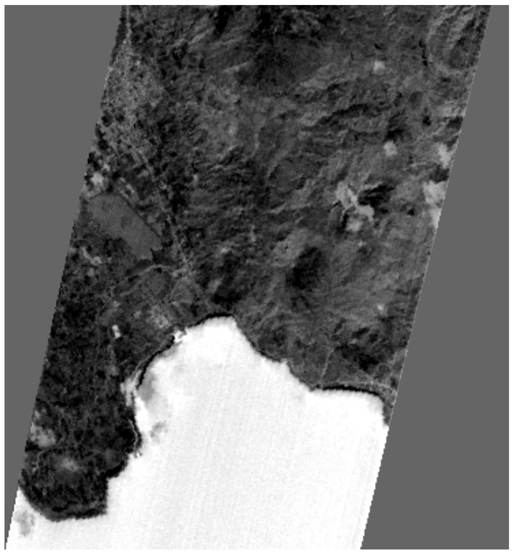

Figure 3.Second MNF band of a hyperspectral image.

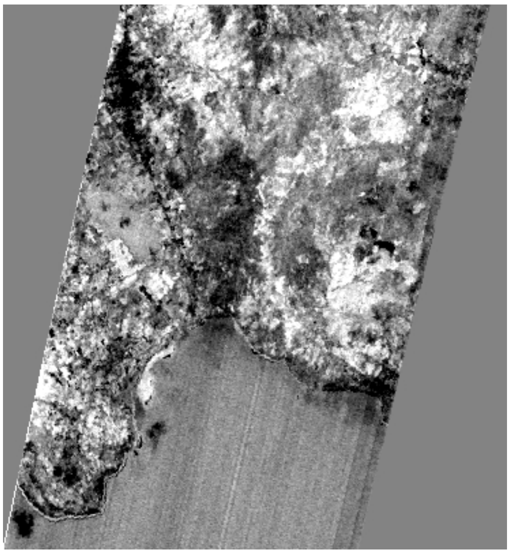

Figure 4. Fourth MNF band of a hyperspectral image.

The outcomes of parallel-pipe analysis are preliminary classification results. A quick verification with known ground truth samples indicates that the overall accuracies are 60% to 70%. At first sight, this may not seem adequate. Further investigation reveals that the low accuracy rates stem from two primary sources. As of an example shown in Fig. 5, most of the target of interest within the polygons created from previous field investigation have been successfully identified during the spectral analysis phase. However, there seem to be a lot of commission errors. Part of the reason for this is because the GIS layer used as ground truth samples does not cover the entire study area. In addition, the creation dates of the GIS data are at least one year old and the target of interest is spreading very fast in the study site.

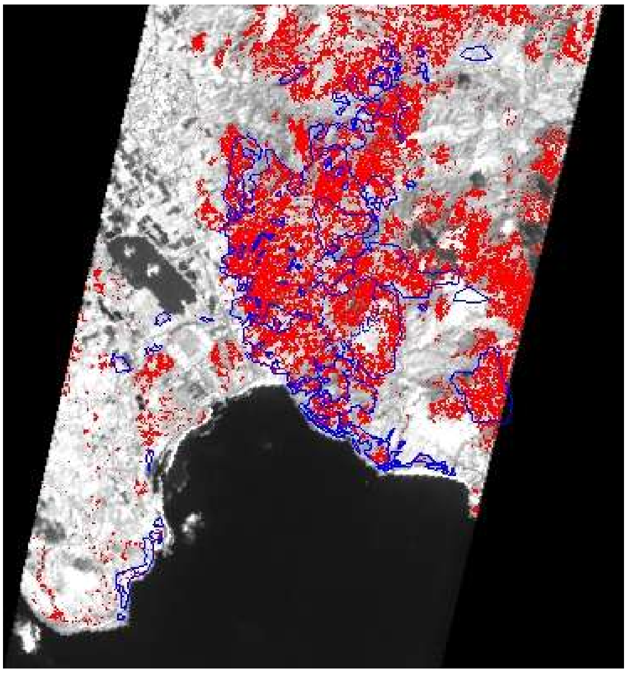

Figure 5. Preliminary result (red) from spectral analysis and known ground truth data (blue).

Another source of the errors comes from the fact that *Leucaena Leucocephala* may exhibit different spectral patterns due to intrinsic characteristic differences. Indeed, there are more than one kind (species or sub-species) of *Leucaena Leucocephala* exist within the study area. Consequently, the variations may cause significant confusion to spectral classifiers.

Albeit all of these, the accuracy can still be improved, especially for errors from the second source (intrinsic characteristic variations). The approach employed in this study to remedy this defect is via texture analysis of high resolution images as described below.

3.2 Analysis of High Resolution Images

Detail examination of the classification results produced in the first analysis phase indicates that spectral classifiers did a poor job in recognizing *Leucaena Leucocephala* with varied characteristics in spectral domains. A primary reason for this defect is because the hyperspectral image has a very broad ground resolution (30m) comparing to the physical sizes of the tree and canopy structures of the target to identify. Therefore, introducing spatial analysis of high resolution data should be a right approach to solve this problem. Accordingly, texture analysis procedures of high resolution images were employed to improve the classification results in spots where spectral analysis failed to produce accurate outcomes.

Figure 6. Texture of target plant in high resolution images.

An example of such texture analysis is shown in Fig. 6. The greens in this image are in fact all *Leucaena Leucocephala*. Because of the difference in population density, trunk heights, and perhaps canopy structures or health statuses, they appear to have different degrees of greeness. This may cause a spectral analyzer to classify them as different classes. However, in spite of differences in spectral appearance, they all have very similar, if not exactly the same, and unique spatial patterns (texture) and are very distinct from other vegetation covers, such as the farmlands and grasslands also shown in the same image. As a result, after the refinement by texture analysis on high resolution images, the accuracy of *Leucaena Leucocephala* detection was increased by at least 15%.

3.3 Future Improvement

First of all, as mentioned above, the spatial (texture) analysis of high resolution images in this study was accomplished through interactive analysis by experienced human interpreters. The top priority will be to computerize the process in order to achieve more degree of automation. Several texture analysis algorithms (e.g., GLCM and CDTM) have been evaluated. In addition, because it requires a significant amount of high resolution data to cover the entire study area, hence the data volume may become too large for a timely and efficient full-scale texture analysis. Therefore, a texture analysis algorithm and procedure with level of detail (LOD) consideration is under development and will be implemented to address this issue.

Secondly, although spectral analysis operating on MNF transformed hyperspectral data can produce reasonable results, there is still room for improvement. Other spectral analysis techniques shall be investigated to explore the possibility of creating a more effective method for spectral analysis. Also, the integration between spectral and texture analysis phases should also be addressed in order to streamline the overall procedure of the system.

4 CONCLUSION

The invasion of alien plant species has caused significant impact to local ecosystems and biodiversity in Taiwan. To better understand the situation and develop strategies to battle against the deterioration of this problem, it is necessary to have an accurate knowledge about the distribution and spreading status and trend of the invasive plants.

This study demonstrates that the coupling of spectral analysis of hyperspectral images and texture analysis on high resolution satellite data is an effective and economic approach to detect specific plant in a mesoscale to large area. The systematic method developed in this research first applies spectral analysis to MNF transformed hyperspectal satellite images according to selected spectral features. The preliminary results are then further improved with texture analysis on high resolution images. Example from this study shows that the combination of the two analysis phases (spectral and texture) can produce a reasonably well accuracy in discriminating *Leucaena Leucocephala* from local vegetation covers in the Kenting National Park and surrounding areas.

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