IMPERVIOUS SURFACE EXTRACTION FROM MULTISPECTRAL IMAGES USING MORPHOLOGICAL ATTRIBUTE PROFILES AND SPECTRAL MIXTURE ANALYSIS

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ABSTRACT

Morphological attribute profiles (MAPs) are one of the most effective methodologies to characterize the spatial information in remote sensing images. This technique extracts components able to accurately describe objects in the surface of the Earth. In this work, we present a new method for impervious surface extraction from multispectral images using morphological attribute profiles. The proposed method first uses morphological profiles to extend Landsat ETM+ images with additional features. Then, we adopt a vegetation–impervious surface–soil (V–I–S) model and extract three pure classes (endmembers) from these images (i.e. vegetation, impervious surface and soil) using the vertex component algorithm (VCA). Finally, linear spectral mixture analysis (SMA) is conducted to extract the impervious surface percentage (ISP). To test the performance of the proposed method, more than 300 test samples including business districts, residential areas and urban roads are randomly selected from QuickBird imagery with very high resolution. The coefficient of determination R^2 is 0.7571, which significantly outperformed other standard techniques in the literature. The obtained experimental results demonstrate that the proposed approach based on morphological attribute profiles can lead to very good extraction and characterization of impervious surfaces.

***Index Terms*—** Morphological attribute profiles (MAPs), impervious surface percentage (ISP), spectral mixture analysis (SMA), vertex component algorithm (VCA).

1. INTRODUCTION

Impervious surfaces are defined as any surface that water cannot infiltrate, and are associated with transportation (streets, highways, parking lots and sidewalks) as well as building rooftops. Impervious surfaces represent a significant index to demonstrate the environmental quality of a city. It is important to estimate the impervious surface percentage (ISP) for regional water environment planning, land use planning, urban ecological researching and urban land use change monitoring. Remote sensing has been an important and effective method for precisely estimating impervious surfaces. Remote sensing data have been applied widely in urban environmental analysis, and therefore numerous methods are exploited for this purpose. Ridd proposed an urban environmental components model in which urban surfaces are expressed as the combination of three different elements: vegetation, impervious surface and soil (V-I-S) [1]. Due to the complex diversity of urban surfaces, a pixel of a remote sensing image generally comprises several different components. As a result, each pixel can be assumed as the mixed spectral reflectance of different types of land covers, in different proportions. Spectral mixture analysis (SMA) is an effective method to analyze urban environments and estimate impervious surfaces [2, 3].

SMA based methods obtained very promising estimation for the impervious surface, however have a critical issue need to be solved. That is, how to select/generate the pure spectral signatures of the considered endmembers. Several researches have focused on addressing this issue due to the high variabilities of endmembers in urban environments. Some studies emphasize the significance of the selection of bands that against the endmembers variations [4, 5]. Others use the multiple endmember spectral mixture analysis to decrease the endmember variation [6]. There are also research take the spatial information into account to address this problem [7].

In this paper, we develop a new method to estimate impervious surfaces in Landsat ETM+ images. Morphological attribute profiles(MAP), proposed in [8], are powerful tools for the extraction of spatial features. MAPs can not only decrease the variability of endmembers, but also extract the characteristic of structure, texture and distribution of remote sensing imageries. In this work, MAPs are used to generate spatial structural information, which is then used to improve the estimation accuracy of impervious surfaces by means of SMA. We illustrate the performance of our newly developed approach in a specific case study focused on the estimation of ISP in the city of Guangzhou, China.

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2. STUDY AREA

We select the city of Guangzhou, China, as our study area (see Fig.1). As the capital of the Guangdong province, Guangzhou is one of the largest cities in the south of China. This area has experienced a fast development during the past 30 years, giving rise to developed urban construction and subsequent damage of natural surfaces. The area consists of many typical types of impervious land covers, such as parking lots, roads and buildings. Additionally, there are also pervious surface in this area, including grasslands, tree/shrubs, croplands and bare soil. The ETM+ images used in this study were acquired in Feb 22, 2008. These data are mostly cloud-free. The images are corrected with ground control points and projected into the UTM WGS84 coordinate system. Moreover, these images are converted to normalized exo-atmospheric reflectance measures with the radiance to reflectance conversion formula. In consideration of negligible atmospheric effects for ISP estimation, we did not apply atmospheric correction [9].

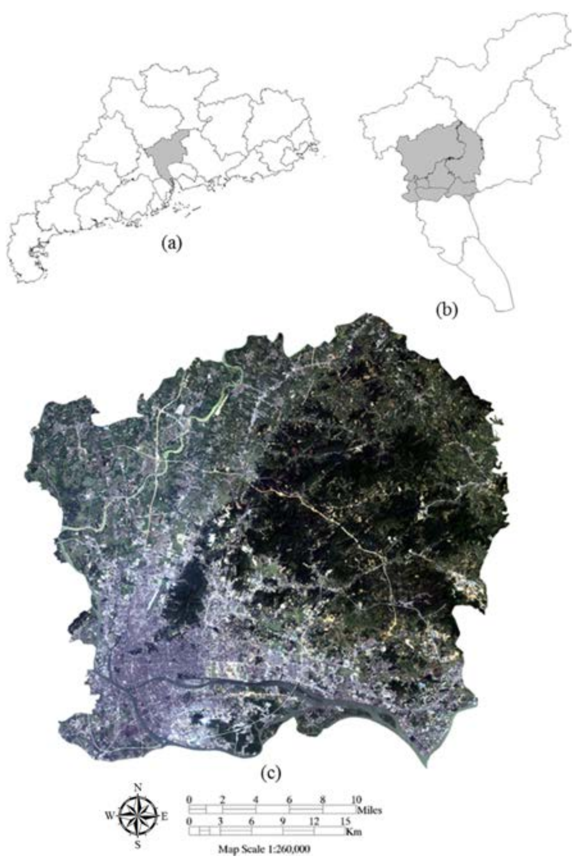

Fig. 1. Study area. (a) Guandong Region. (b) Guangzhou City. (c) Landsat ETM+ imagery.

3. PROPOSED METHOD

The basic idea of our method is to apply MAPs [8] to extract the structural information of the considered multispectral images. The multilevel characteristics can be obtained by accumulating such structural information. Compared with natural land covers, artificial land covers exhibit unique spatial characteristics. For example, a building (as an individual entity with small spatial scale) will present certain construction attributes, while a number of tightly arranged houses (covering a larger spatial scale) will present regular contextual information. MAPs can extract the spatial characteristics of artificial land covers. This is done by thinning and opening operations in grayscale images. Given a certain set of parameters, MAPs performs a series of morpholgical profile operations using the attributes of each connected component. These attributes include area, standard deviation [10], length of the diagonal of the bounding box, and moment of inertia. Synthetic multilevel spatial features can be then acquired by stacking the different types of attributes extracted from the images together. In this work, we choose high albedo, low albedo and vegetation as three fundamental endmembers for analyzing the considerd. The first 6 bands of the ETM+ images are extended into 18 bands when using MAPs to extract spatial information. Then three endmembers are extracted using the vertex component algorithm (VCA) [11]. Finally, the abundance images are acquired using a fully constrained least-squares (FCLS) method. After removing the water area using NDWI [12], the impervious surfaces are eventually acquired by adding low albedo and high albedo together.

4. RESULTS AND ANALYSIS

4.1. Accuracy analysis

The biological composition index (BCI) algorithm in [13], were used for comparison. The obtained impervious surface maps from the ETM+ image are illustrated in Fig.2. As demonstrated by Fig.3(a) and Fig.3(b), the R^2 of ISP using the proposed SMA model is 0.7571, achieving better performance than BCI (0.695). Moreover, by comparing Fig.2(a) and Fig.2(b), we can see that the difference between bright imperviousness and dark imperviousness is more apparent in the proposed method than in the BCI. Some land entities are marked out in red circles, verifying the effectiveness of discriminating the bright imperviousness and dark imperviousness. The bright imperviousness is brighter, ranging between 0.8 and 1.0 approximately, while the dark imperviousness ranges between 0.5 and 0.7. On the contrary, the differences in albedo estimated by BCI are not so relevant, so that it is very difficult to distinct between bright and dark imperviousness directly.

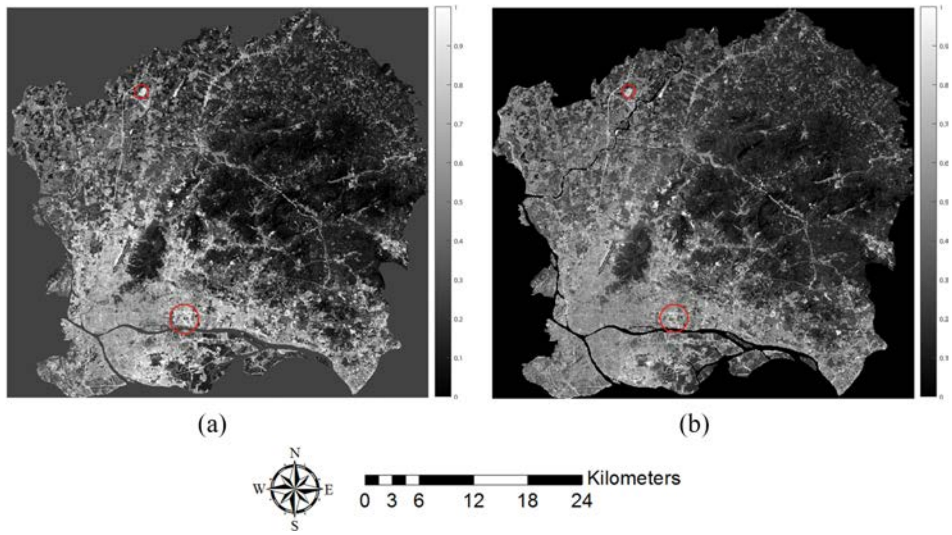

Fig. 2. (a) Estimation of ISP by the proposed method. (b) Distribution of ISP by BCI.

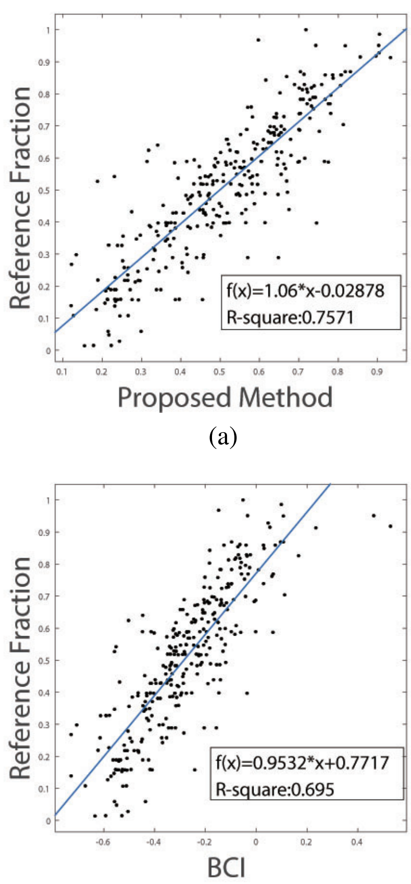

Fig. 3. Scatterplots between the impervious surface obtained from different methods for the ETM+ image. (a)Reference fraction vs proposed method, (a)Reference fraction vs BCI

4.2. Spatial distribution of impervious surfaces

To provide an intuitive visualization of the estimations obtained for different types of land covers, we generated a false color image using three endmember fractions (see Fig.4), where red color represents areas with high albedo, green color represents areas with vegetation, and blue color represent areas with low albedo. As demonstrated by Fig.4, ISP distribution is mainly located in the southwest area of Guangzhou. Apparently, most of the high albedo areas appear as linear and point-like entities, mainly highways, asphalt roads, and other major transport routes. Most of such land cover types are characterized by a relatively high reflectance, mainly because they consist of cement, asphalt and metal. Low albedo regions often appear as uniform block entities, generally distributed around the high albedo regions. This comprises residential areas and other small buildings. Vegetation appears mainly in the northern areas of Guangzhou (Huangpu and Baiyun districts).

5. CONCLUSIONS AND FUTURE WORK

In this paper, we have developed a new method for estimating the impervious surface percentage using morphological attribute profiles (to extract spatial information) and spectral mixture analysis (to characterize spectral information). We divide the urban region into three components: high albedo, low albedo and vegetation. Spectral endmembers corresponding to these components are extracted automatically by the vertex component analysis algorithm, and abundance fractions are obtained using the fully constrained least-squared method. Impervious surface can be eventually acquired by adding low albedo and high albedo together after removing the water areas. Our experimental results, using Landsat ET-

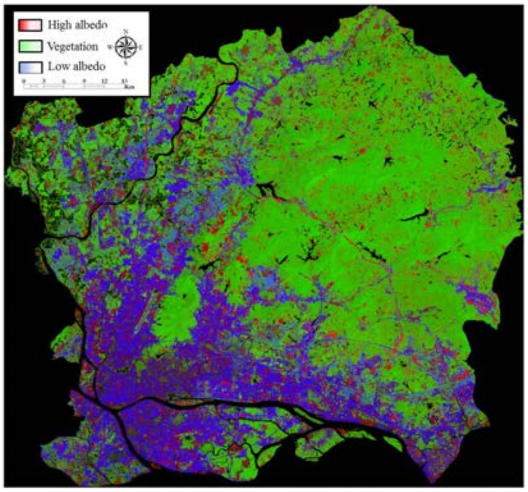

Fig. 4. False color image, where red color represents areas with high albedo, green color represents areas with vegetation, and blue color represent areas with low albedo in Guangzhou, China.

M+ data sets collected over Guangzhou, China, demonstrate that: (1) by using morphological attribute profiles, we can not only extract the spatial information effectively in urban environments, but also decrease the variabilities of endmember in remote sensing images; (2) we can also quickly and precisely extract the endmembers that represent the different land cover types, eliminating the influence of manual procedures; and (3) spectral mixture analysis provides an effective mechanism to estimate the impervious surface with rapidness and simplicity, achieving good accuracy when endmembers are accurately extracted. As with any new approach, there are also some limitations that should be addressed in future developments. Specifically, the complicated land covers existing in urban environments, such as shadows of buildings, sand, rare vegetation, etc. may introduce significant spectral mixture reflectance. Such factors may influence the estimation of impervious surfaces to a certain extent. How to mitigate these effects will be the main focus of our future research developments.

6. REFERENCES

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