ISPRS Journal of Photogrammetry and Remote Sensing 124 (2017) 27–39

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Multi-source remotely sensed data fusion for improving land cover classification

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ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form 12 October 2016
Accepted 20 December 2016

Keywords:
Land cover classification
Remote sensing
Data fusion
Temporal and angular features

ABSTRACT

Although many advances have been made in past decades, land cover classification of fine-resolution remotely sensed (RS) data integrating multiple temporal, angular, and spectral features remains limited, and the contribution of different RS features to land cover classification accuracy remains uncertain. We proposed to improve land cover classification accuracy by integrating multi-source RS features through data fusion. We further investigated the effect of different RS features on classification performance. The results of fusing Landsat-8 Operational Land Imager (OLI) data with Moderate Resolution Imaging Spectroradiometer (MODIS), China Environment 1A series (HJ-1A), and Advanced Spaceborne Thermal Emission and Reflection (ASTER) digital elevation model (DEM) data, showed that the fused data integrating temporal, spectral, angular, and topographic features achieved better land cover classification accuracy than the original RS data. Compared with the topographic feature, the temporal and angular features extracted from the fused data played more important roles in classification performance, especially those temporal features containing abundant vegetation growth information, which markedly increased the overall classification accuracy. In addition, the multispectral and hyperspectral fusion successfully discriminated detailed forest types. Our study provides a straightforward strategy for hierarchical land cover classification by making full use of available RS data. All of these methods and findings could be useful for land cover classification at both regional and global scales.

1. Introduction

Land cover is a fundamental variable that affects and links many parts of human and physical environments (Foody, 2002; Running, 2008; Turner et al., 2007). It has been well established that land cover patterns and changes reflect the underlying natural, ecological and social processes and play a major role in climate change and biodiversity conservation at global and regional scales. Accurate and timely land cover classification maps are of great importance to global change studies, as they can provide essential knowledge for understanding the Earth's dynamics including climate change (Feddema et al., 2005; McAlpine et al., 2009), biodiversity conservation (Gillespie et al., 2008; Hansen and DeFries, 2007), and the interaction between social activities and terrestrial changes (Running, 2008; Yue et al., 2003).

Remotely sensed (RS) data from onboard sensors share the ability to quickly provide large-scale and easily accessible information about the spatial variability of the terrestrial surface, and they have proved to be the most useful and effective approaches in numerous earth observation applications (Gong et al., 2013; Hansen et al., 2000), especially in land cover thematic mappings. Satellite-based land cover classification has been an ongoing hot research topic within the remote sensing community (Foody, 2002; Hansen et al., 2013; Lu and Weng, 2007). In recent decades, many advances have been made in both algorithm development and the practical applications of land cover classification. Many land cover classification products derived from RS data at global and regional scales have been produced, and are freely available at spatial resolutions from 30 m to 1 km. Representative products include the 1-km International Geosphere-Biosphere Programme data and infor-

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http://dx.doi.org/10.1016/j.isprsjprs.2016.12.008
0924-2716/

mation system cover (IGBP-DISCover) map derived from the monthly normalized difference vegetation index (NDVI) composites of the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data (Loveland et al., 2000), the 1-km University of Maryland (UMD) land cover map derived from the NOAA AVHRR data sets (Hansen et al., 2000), the 1-km Global Land Cover 2000 (GLC2000) maps derived from the monthly NDVI data from Satellite Pour l'Observation de la Terre Vegetation (SPOT-VGT) data (Bartholomé and Belward, 2005), the 1-km Moderate Resolution Imaging Spectrometer (MODIS) land cover map derived from the 1-km MODIS product (Tateishi et al., 2010), the 500-m MODIS land cover maps derived from the MODIS data (Friedl et al., 2002, 2010), the 300-m GlobCover land cover maps derived from the bimonthly MEdium Resolution Imaging Spectrometer (MERIS) dataset (Arino et al., 2012), and the 30-m global land cover products derived from the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data (Chen et al., 2015c; Gong et al., 2013).

However, most of the existing land cover products are at coarse resolutions in spatial details and update frequency and land cover classification derived from the RS data remains a challenge (Huang et al., 2013), given that many factors such as landscape heterogeneity, image preprocessing, classification methods, and the post-classification process may affect the success of a complete classification (Lu and Weng, 2007). Moreover, the RS data acquired from the multi-source sensors have varying spatial, temporal, spectral, and angular resolutions. Thus, the selection of RS data is a critical step in carrying out a successful classification.

The inclusive features of the optical RS data in the classification procedure can be categorized into five classes. The first class is spatial information. High-spatial-resolution images such as Quick Bird and IKONOS images certainly provide more detailed spatial information of the terrestrial surface. However, their high expenses barricade the data accessibility. Therefore, the freely accessible medium-spatial-resolution images such as Landsat and ASTER images are widely used. The second class is spectral information. Differences among spectral signatures are used to help classify RS images into classes of landscape features, as the spectral signatures of different features have different shapes. The hyperspectral instruments have contiguous narrow wavelength bands (about 10 nm per band) and are able to capture much more detailed spectral signatures than the multispectral sensors (about 100 nm per band). The third class is temporal information. Accurate and timely information describing the nature and extent of the terrestrial surface and its changes over time is critically important to produce finer land cover classification maps. For example, Landsat data integrating the temporal features from the coarse resolution data have been proposed to improve land cover classification (Chen et al., 2015b; Jia et al., 2014). The fourth class is angular information. Studies have indicated that bidirectional reflectance distribution function (BRDF) information can be used to complement spectral signatures to improve land cover classification accuracy (Brown de Colstoun and Walthall, 2006). For example, Huang et al. (2012) proposed to improve Landsat-based urban mapping by integrating multi-angle observation from Multi-angle Imaging SpectroRadiometer (MISR) data. The fifth class is topographic information. Wang et al. (2012) reported that combining the topographic elevations and slopes into the classification procedure could reduce misclassifications of different land cover types in mountainous areas.

Although multi-source RS data have demonstrated their great ability and potential for land cover classification at both global and regional scales, few studies have investigated which RS feature contributes most to accurate land cover classification from the perspective of RS feature selection. Moreover, the great utility of unified RS data fusion in land cover classification has been limited addressed. Thus, in this study, we addressed these ubiquitous challenges with two objectives: (i) to explore the potential of multi-source RS data fusion for producing a better land cover classification and (ii) to investigate the effect of different RS features on the improvement of land cover classification accuracy.

The remainder of this paper proceeds as follows. Section 2 gives a brief description of the study site and the selected dataset. Sections 3 and 4 provide a detailed illustration of the methods and results. We discuss the implications of our approach in Section 5, and offer some conclusions and major findings in Section 6.

2. Study area and data

2.1. Study area

We selected Beijing, which is located in the northern part of the North China Plain (39°26′–41°03′N, 115°25′–117°30′E), covering an area of approximately 16410.54 km^2, as our study site (Fig. 1). Beijing is in a temperate climatic zone, characterized by four distinct seasons with hot and humid summers, cold and dry winters, rapidly warming and dry springs, and crisp and short autumns. There are open alluvial plains in the south and east, and the northern, northwestern, and western sides of Beijing are sheltered by hills and mountains. The elevation of the study site ranged from 10 to 2303 m (Jia et al., 2014). The various land cover types in this area including forest (coniferous and broadleaf), impervious areas, water, cropland, bare land, and grassland, which provided us with a representative study area to test land cover classification performance in a hierarchical framework.

2.2. Data

The primary data used in this study comprised Landsat OLI, MODIS, HJ-1A, and ASTER GDEM. Table 1 summarizes the characteristics of the spatial-temporal-spectral resolutions of these sensors. A brief description of the selected dataset is provided below.

Four cloud-free sets of Landsat-8 OLI data over the entire Beijing area were acquired in this study. One scene was used for the prediction requirement at the day of year (DOY) 132, and the other three scenes were used for validation at DOY 273, 305, and 329, respectively. Each scene included two adjacent paths (path/row: 123/32 and 123/33) covering the whole study area.

We used two types of MODIS MCD43 series products in our study. First, the MCD43A4 data provided 500-m reflectance data adjusted using a bidirectional reflectance distribution function (BRDF) to model the nadir-view values, with observations every 8 days. Second, we used the MCD43A1 BRDF/Albedo Model Parameters Product acquired at DOY 129 (*i.e.*, the nearest temporal date to the base date of Landsat OLI). Three kernel parameters of the MCD43A1 data could be used in a forward version of the Kernel-driven model to reconstruct the surface anisotropic effects and correct directional reflectance to a common view geometry. Fig. 2 shows the position contrast of the seven selected bands of Landsat OLI and MODIS data in the electromagnetic spectrum.

The China environment satellite HJ-1A carried a spaceborne hyper-spectral imager (HSI), and a multi-spectral sensor, the charge-coupled device (CCD). Fig. 3 shows the position contrast of the HJ-1A CCD and HSI bands in the electromagnetic spectrum. In this study, the HJ-1A HSI and CCD images acquired on May 12, 2013 were selected.

We used the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 1 (GDEM V1) for topographic correction and the calculation of the topographic variables. ASTER GDEM provided 30-m pixel spacing and approximately 20-m vertical accuracy of terrestrial eleva-