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Fine crop mapping by combining high spectral and high spatial resolution remote sensing data in complex heterogeneous areas

Mingquan Wu [a,*], Wenjiang Huang [b], Zheng Niu [a], Yu Wang [c], Changyao Wang [a], Wang Li [a], Pengyu Hao [a], Bo Yu [b]

[a] *The State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, P.O. Box 9718, Datun Road, Chaoyang, Beijing 100101, China*
[b] *Laboratory of Digital Earth Sciences, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China*
[c] *Beijing Twenty-First Century Science & Technology Development Co., Ltd., Beijing 100083, China*

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ABSTRACT

In complex heterogeneous areas, it is difficult to map crops with high accuracy using only high spatial resolution or only high spectral resolution remote sensing data. Because the spectral resolution of high spatial resolution data is too low, the spectral differentiations of different vegetation types are very small in high spatial resolution data. It is hard to distinguish between different vegetation types using high spatial resolution data. For high spectral resolution remote sensing data, it is hard to exclude linear objects like roads, bridges and drains from crops due to the low spatial resolution of these data. To address this problem, a novel object-based fine crop mapping method by combining high spatial and high spectral resolution remote sensing data for heterogeneous areas was proposed and validated in Suzhou city, Jiangsu province, China. First, pure crop polygons were derived from a 0.5 m aerial data. Due to the high spatial resolution, non-cultivated land could be easily isolated from arable land. Then, a Hyperion data was used to classify crops for each of the pure crop polygons. The results show that this method can map crops in complex heterogeneous areas with an overall accuracy higher than 95%, which is much higher than the accuracy of maps classified using only high spatial resolution data or only high spectral resolution data, which have an overall accuracy of 58.78% and 77.54%, respectively.

1. Introduction

As a remote sensing satellite is able to acquire large-area data recurrently, it is one of the main technologies used for crop mapping (Homolova et al., 2013). Crop fields mapped with remote sensing imagery have been widely used by government departments all over the world, for example in China, America, the European Union and Korea (Hao et al., 2015; Waldner et al., 2015; Yusoff and Muharam, 2015). Usually, crops can be classified by specific features using remote sensing technology. Spectral characteristics, temporal characteristics and spatial characteristics are the main features used for crop mapping in optical remote sensing. As different land cover types have different spectral curves, spectral characteristics are the main features used for crop mapping in optical remote sensing (Everitt et al., 2013; Landmann et al., 2015). Temporal characteristics are another widely used feature for crop mapping in optical remote sensing. It is widely used to map crops fields using multi-temporal remote sensing data (Zheng et al., 2012). Phenology information is one of the most frequently used temporal features for crop mapping (Li et al., 2014; Siachalou et al., 2015). It is usually used for mapping crops using time series of low spatial resolution data such as Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Estel et al., 2015; Zhang et al., 2006, 2012). Time series analysis is the main method using temporal features mapping (Bharathkumar and Mohammed-Aslam, 2015). Several methods like Maximum Likelihood, Spectral Angle Mapper, Support Vector Machine and IsoData were proposed for classification using spectral or temporal features of land cover types (Bannari et al., 2015; Geipel et al., 2014; Gong et al., 2013; Yang et al., 2015). With the launch of high spatial resolution remote sensing satellites such as Quickbird, Ikonos, and Worldview

Abbreviations: AVHRR, Advanced Very High Resolution Radiometer; MODIS, Moderate Resolution Imaging Spectroradiometer; SAM, Spectral Angle Mapper; GPS, global positioning system; GCPs, Ground Control Points; GF-1, Gaofen satellite No. 1; PMS, Panchromatic and multispectral sensors; FLAASH, Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes; USGS, the U.S. Geological Survey; ROIs, regions of interests.

* Corresponding author.
E-mail address: wumq@radi.ac.cn (M. Wu).

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1/2, high spatial resolution remote sensing data has been widely used (Low and Duveiller, 2014). Several classification methods, like the object-based crop classification and texture analysis method, were proposed for land cover mapping using the spatial features extracted from high spatial resolution data (Li et al., 2015; O'Connell et al., 2015).

However, due to the complex land cover situation, crop mapping accuracy was not very high if only one kind of feature was used, especially in complex heterogeneous areas (O'Connell et al., 2015). For example, due to the lower spectral resolution, the spectral differentiations of different crops were small and unable to be used to map crops even in high spatial resolution satellite data like Worldview and Quickbird (de Castro et al., 2013; Mukashema et al., 2014; Ozdarici-Ok et al., 2015). Due to the similar phenology features of different crops, the temporal characteristics of different crops were also very similar in complex heterogeneous areas (Wu et al., 2015e). And although the spectral features of different crops can be distinguished in high spectral resolution satellite data like Hyperion data, these data were also not suitable for mapping crops in complex heterogeneous areas because linear objects like roads, drains and ridges are easy to be misclassified as crops due to low spatial resolution of Hyperion data (Galloza et al., 2013).

To address this problem, a good solution is to combine spectral characteristics, temporal characteristics and spatial characteristics. Several studies have proposed to combine the spatial and temporal information for land cover mapping (Wu et al., 2015d, 2016). Wu et al. introduced a Spatial and Temporal Data Fusion Approach (STDFA) to combine medium spatial resolution data and high temporal resolution data to generate daily synthetic medium spatial resolution data (Wu et al., 2015a, 2012). They also demonstrated that crops mapping accuracy can be improved by combining medium spatial resolution data and high temporal resolution data (Wu et al., 2015e). However, due to the 30 m spatial resolution, the issue of misclassified linear objects was not addressed and limited the application of this method in complex heterogeneous areas (Wu et al., 2015e). Linear objects were classified as crop areas which enlarged the areas of crop lands. These methods also do not work when there are crops with similar phenology. Lier et al. proposed an approach to map shrubs by combining IKONOS data and Landsat Thematic Mapper (TM) data (van Lier et al., 2009). They found that the combination of IKONOS and Landsat data is useful for mapping shrubs as it increases the spatial distribution of the samples and consequently, classification accuracy (van Lier et al., 2009). However, this method also doesn't work well in complex heterogeneous areas (van Lier et al., 2009).

To solve these problems, the aim of this paper is to propose a novel fine crop mapping method by combining high spatial and high spectral resolution remote sensing data. Pure polygon data were derived from high spatial resolution aerial data which can distinguish crop areas with linear objects very easily. The high spectral resolution Hyperion data were used to classify each crop type. Therefore, the objectives of this study are (1) to propose a novel object-based fine crop mapping method by combining high spatial resolution and high spectral resolution remote sensing data in heterogeneous areas; and (2) to compare maps classified solely with 2 m Gaofen imagery or Hyperion imagery to maps classified by combining with high spatial resolution and high spectral resolution data.

2. Study area and data pre-processing

2.1. Study area

A 4 km × 4 km integration area of urban and rural in Suzhou city, Jiangsu province, China, was selected as the study area (Fig. 1). This study area is about 7 km from the Suzhou city downtown area. Suzhou city is a developed region in China. There are more than 5 million people in Suzhou city downtown. Although this area belongs to the Yangtze Plain, the land cover types in this area are very heterogeneous. The polygons in this area are usually smaller than 5000 m^2. Moreover, as this area is very near the Suzhou city downtown, many farm lands were developed to grow economic plants, such as commercial turf, temporary greenhouse and commercial woodland. The commercial turf was planted and eradicated many times every year. The temporary greenhouse is covered with a thin film in the winter to plant vegetables. In other seasons, because the climate is warm, no film is needed to plant vegetables. The commercial woodland is planted in farm lands for several years before it is sold. Other farm lands were developed to plant wheat from winter to sprint. Due to the main objective of this study is to map crops, other land cover types (e.g. building land, grass, water and trees) which does not occupy arable land are divided into non-cultivated land. So the main land cover types in this study area are wheat, commercial turf, temporary greenhouse, commercial woodland and non-cultivated land. Suzhou has a subtropical monsoon maritime climate. The minimum monthly average temperature of Suzhou is 2.5 °C. Thus, vegetation types like wheat, commercial turf and commercial woodland are evergreen which lead to little effect of phenology information on land cover types classification.

2.2. Data and pre-processing

2.2.1. Aerial data

A 0.5 m aerial image acquired in March 2014, was used in this study. It contains three bands (Red, Green and Blue). Due to the high spatial resolution, each polygon can be identified very well. The aerial image was georeferenced using 16 Ground Control Points (GCPs) selected from a 1:500 topographic map with a position error within 0.7 aerial data pixels. Usually the land cover change is very slow. And due to the higher price, this high spatial remote sensing data can usually be used for 5 years in crop mapping (Wang et al., 2015). Although the aerial image was acquired in March 2014, it can also be used for mapping crops in 2015.

2.2.2. GF-1 PMS data

The Gaofen No. 1 (GF-1) satellite is the first satellite for the Chinese high-resolution earth observation system of national science and technology major projects. It was launched on 26 April 2013. Two Panchromatic and multispectral sensors (PMS) sensors were onboard the GF-1 satellite. It can acquire panchromatic images and multispectral images at a spatial resolution of 2 m and 8 m with four-day intervals, respectively (Table 1).

A GF-1 PMS image acquired on January 1, 2015, was used to map crops in this study. This GF-1 PMS image is obtained in clear-sky conditions and provides good data quality. It was atmospherically corrected using the Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) Atmospheric Correction Model in software ENVI 5.2. Then the panchromatic and multispectral data was fused using the PC spectral sharpening method. Finally, the 2 m fusion image was georeferenced using a second-order polynomial warping approach based on the selection of 20 GCPs, using the warped aerial image with the nearest neighbor resampling method with a position error within 0.6 fusion image pixels.

2.2.3. Hyperion data

A Hyperion image acquired on February 11, 2015, was used as high spectral resolution remote sensing data. The Hyperion sensor can acquire images with a spatial resolution of 30 m and a spectral resolution of 10 nm. There are 242 bands ranging from 355 to