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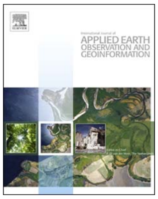

Crown-level tree species classification from AISA hyperspectral imagery using an innovative pixel-weighting approach

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ABSTRACT

Crown-level tree species classification is a challenging task due to the spectral similarity among different tree species. Shadow, underlying objects, and other materials within a crown may decrease the purity of extracted crown spectra and further reduce classification accuracy. To address this problem, an innovative pixel-weighting approach was developed for tree species classification at the crown level. The method utilized high density discrete LiDAR data for individual tree delineation and Airborne Imaging Spectrometer for Applications (AISA) hyperspectral imagery for pure crown-scale spectra extraction. Specifically, three steps were included: 1) individual tree identification using LiDAR data, 2) pixel-weighted representative crown spectra calculation using hyperspectral imagery, with which pixel-based illuminated-leaf fractions estimated using a linear spectral mixture analysis (LSMA) were employed as weighted factors, and 3) representative spectra based tree species classification was performed through applying a support vector machine (SVM) approach. Analysis of results suggests that the developed pixel-weighting approach (OA = 82.12%, Kc = 0.74) performed better than treetop-based (OA = 70.86%, Kc = 0.58) and pixel-majority methods (OA = 72.26, Kc = 0.62) in terms of classification accuracy. McNemar tests indicated the differences in accuracy between pixel-weighting and treetop-based approaches as well as that between pixel-weighting and pixel-majority approaches were statistically significant.

1. Introduction

Urban forests play an important role in urban ecological environments in many ways, including moderating local climate (Deng et al., 2011), improving air quality (Nguyen et al., 2015), reducing stormwater runoff (Armson et al., 2013), and ameliorating urban heat island effect (Armson et al., 2012). The contribution of urban forests, however, depends on tree species and their spatial distributions (Alonzo et al., 2014). As an example, walnut and poplar have high capacity for carbon dioxide (CO2) sequestration (Proietti et al., 2016), holm oak has the high potential for particle matter (PM) removal (Blanusa et al., 2015), and sugar maple is used as an ornamental tree or the best source of maple sugar (Whitney and Upmeyer, 2004). In addition, tree species identification is beneficial for forest pest management. For instance, ash trees are widely planted in North American countries due to their high tolerance to surrounding environments (MacFarlane and Meyer, 2005), but tens of millions of them were killed by the exotic bark beetle-emerald ash borers (Agrilus Planipennis Fairnaire, EAB) (Flower et al., 2013; Pugh et al., 2011). Therefore, ash tree identification is helpful for early detection and response planning for EABs. As the diversity of tree species is a key component for urban forest management (Conway and Vander Vecht, 2015), accurate species mapping is critical for biological diversity investigation (Carlson et al., 2007), effective forest management (Banskota et al., 2011; Plourde et al., 2007), and physiological stress monitoring (Wu et al., 2008).

Hyperspectral data is considered effective for mapping tree species as it can measure subtle variability in spectral reflectance from leaf to crown scales, largely due to their very high spectral resolution and wide range of electromagnetic spectrum. As a result, hyperspectral data have been widely applied in mapping tree species in urban forests (Alonzo et al., 2013; Green et al., 1998), temperate forests (Heinzel and Koch, 2012), tropical rainforests (Clark et al., 2005), and mountainous forests (George et al., 2014). Species classification has been often carried out at leaf, pixel, sub-pixel, and crown levels. In particular, leaf-level classification emphasizes on differentiating tree species based on the variations of spectral reflectance of leaf samples. Shang and Chisholm (2014) successfully classified seven eucalyptus species in Australia with the best classification accuracy of 94.7%. Clark et al. (2005) achieved

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89.5%–100% leaf-scale classification accuracy in discriminating seven emergent tree species in a tropical forest by using linear discrimination analysis (LDA) and optimal bands. The relatively pure leaf-level spectra can produce accurate classification accuracy by maximizing between-species spectral variability and minimizing within-species variability. Leaf-level tree species classifications, however, cannot be applied to a large geographic scale as they are labor intensive and time consuming.

Pixel-level classifications have also been employed for tree species classification due to its easiness for implementation and interpretation. Clark and Roberts (2012) classified seven tropical rainforest tree species in Costa Rica from HYperspectral Digital Imagery collection Experiment (HYDICE) data using random forest classifiers. George et al. (2014) classified six broadleaved evergreen and conifer forest tree species in western Himalaya using space-borne earth observation-1 (EO-1) Hyperion dataset. Jones et al. (2010) mapped eleven tree species in the coastal Pacific Northwest, Canada through applying a pixel-level fusion of hyperspectral imagery, a LiDAR derived canopy height model, and a canopy volumetric profile. Dalponte et al. (2012) improved tree species classification in the Southern Alps through integrating LiDAR derived height distribution information and hyperspectral imagery at the pixel level.

Although with some success, pixel-level classification ignores the negative impact of the mixed pixel problem (Lu and Weng, 2004), which may lead to the “salt and pepper” effect in the final classification result (Yu et al., 2006). That is, an individual pixel may be assigned to a class highly different from their neighbors’ classes. Subpixel-level classification approaches, therefore, improve tree species classification than traditional per-pixel approaches in dealing with mixed pixels (Huguenin et al., 1997). Subpixel-level classification extracts the proportion of individual land covers of interest within a pixel and results in more detailed classification results. Bai et al. (2012) employed a linear spectral unmixing approach for forest cover estimation and obtained better results than conventional spectral angle mapper (SAM). Somers et al. (2009) presented a nonlinear spectral mixture analysis (NSMA) for tree cover estimates in orchards. Roberts et al. (1998) developed multiple endmember spectral mixture analysis (MESMA) to map California chaparral in the Santa Monica Mountains. Further, Somers et al. (2010) applied a weighted multiple endmember Spectral Mixture Analysis (wMESMA) to monitor the level of defoliation of Eucalyptus, and achieved improved results when compared to the simple SMA.

Crown-level classification is increasingly demanded in comparison with leaf level, pixel level, and subpixel level classifications. On the one hand, the species at the individual tree level is often considered as the management unit in practical forest application (Dalponte et al., 2013). On the other hand, the object-oriented method can overcome the limitations of pixel-level classification, such as spatial heterogeneity and mixed-pixel problem (Ke et al., 2014; Whiteside and Ahmad, 2005). Several methods have been developed for crown-level species classification. Clark et al. (2005) linearly averaged the pixel spectra within a manually-delineated crown area as the crown-scale spectra for tropical rain forest species classification, and the highest crown-scale classification accuracy of seven species reached 92% with the linear discriminant analysis (LDA) and 30 optimal bands. Zhang and Qiu (2012) developed a treetop-based approach for classifying 40 species classification in an urban forest and resulted in an overall accuracy of 69%. Rather than averaging all the pixels within a crown to calculate the crown-scale spectra, the treetop-based method extracts the spectra of the highest pixel per crown as the crown-scale spectra. Similarly, Dalponte et al. (2013) conducted a pixel-majority approach for classifying four species in a boreal forest. With this approach, each individual tree crown was assigned to a class if the majority of the pixels with that crown were assigned to that particular class. Further, Alonzo et al. (2013) classified 15 urban forest species with only pixels with normalized different vegetation index (NDVI) values higher than a threshold, and reached an overall accuracy of 86%. Alonzo et al. (2014) integrated Hyperspectral imagery with LiDAR data for mapping 29 tree species in Santa Barbara, California, USA, and an overall accuracy of 83.4% was reported.

Numerous algorithms, including average pixel method, treetop method, and pixel-majority method (Clark et al., 2005; Dalponte et al., 2013; Zhang and Qiu, 2012), have been proposed for crown-level tree species classification. However, their accuracies were much lower than those with leaf-level classifications. Leaf spectra, which are often obtained at the laboratory condition, are relatively pure and have proven effective in discriminating tree species (Shang and Chisholm, 2014). Crown-scale spectra, however, have lower purity due to the interference of mixed pixel problem and double-side illumination problem. Tree shadows, gaps, trunks, branches, and underlying objects may lead to mixed pixel problem, while the illuminated side and the shaded side of each tree crown may produce different spectral signature and therefore lead to the double-side illumination problem (Clark et al., 2005; Shang and Chisholm, 2014; Zhang and Qiu, 2012). This lower purity of crown spectra, therefore, may contribute to the lower classification of tree species at the crown level. In order to address this issue, we developed an innovative method to extract relatively pure crown-scale leaf spectra, which may potentially improve tree species classification accuracy. Specific aims of this paper are: 1) to segment individual crowns using LiDAR derived canopy height model, 2) to calculate the weighted crown-scale spectra from AISA hyperspectral imagery using illuminated-leaf fraction at each pixel as a weighting factor, 3) to classify tree species by applying SVM classifier to the new generated crown-scale spectra. In order to assess the improvement of the pixel-weighting approach in classifying tree species, the treetop-based and pixel-majority approaches will be carried out for a comparative analysis.

2. Methodology

2.1. Study area

The study area is located to the southeast of the University of Wisconsin-Milwaukee (43.07N, 87.87W), Milwaukee City, Wisconsin, United States (see Fig. 1). Milwaukee is an attractive urban center with an urban street grid system. Residential lands account for the largest of all land uses followed by public, commercial, manufactory, and transportation lands. Trees cover 21.6% of Milwaukee city, and the most important species include European bucktborn, Norway Maple, Boxelder, Ash, American elm, Honeylocust, etc (Facts). The rich and diversity of the urban forest help improve air quality by removing pollutants and reducing energy consumption, and mitigate climate change by sequestering atmospheric carbon. The study site has a geographical area of 300 m*700 m, covering 5 street blocks, a residential neighborhood with bungalows, two-family duplexes, and larger apartment buildings for both long-term residents and student populations. The ground surface is flat without significant fluctuation and the average elevation is about 200 m above sea level. This area is dominated by Ash (*Fraxinus* spp.), Maples (*Acer* spp.), Oak (*Quercus* spp.), and some other scattered species, such as Honeylocust (*Gleditsia* spp.) and Pine (*Pinus* spp.). In particular, ash trees are susceptible to the exotic beetle: emerald ash borer (*Agrilus planipennis*, EAB), which have killed tens of millions of native ash trees in North America (McKenney et al., 2012). The heights of trees along the roads are approximately 5–25 m.

2.2. Dataset

Both AISA hyperspectral imagery and LiDAR data were simultaneously collected by Terra Remote Sensing Inc. (TRSI) in August 2008. The choice of data acquisition date is due to two factors. First, as more leaves are present in August, the interference from shadows, gaps, trunks, branches, and other underlying objects on the crown spectra is less when compared to other seasons. Second, identifications of ash trees attacked by EABs are easier due to the significant spectral