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An angular vegetation index for imaging spectroscopy data—Preliminary results on forest damage detection in the Bavarian National Park, Germany

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ABSTRACT

A vegetation index (VI) is presented which is calculated as the inner angles of a triangle. The triangle is spanned between three distinct points (on a spectral curve of imaging spectroscopy data) which are defined for each individual pixel by the wavelength (x-axis) and the reflection value (y-axis). The ideal wavelengths of the three points are dependent on the response variable investigated. The case-study within this paper in which this angular VI is applied, aims at the development of an index to automatically detect spruce bark beetle infections in the Bavarian National Park, Germany. In order to determine the optimum wavelengths to separate damaged from non-damaged trees the three-angle-indices (TAIs) for all possible combinations of available wavelengths of HyMap imaging spectroscopy data in the vis–NIR-region (0.455–0.986 μm) were calculated. The resulting 27,417 images served as input predictor variables to a genetic algorithm (GA) which used nearest centroid classifier as fitness functions to detect the most stable predictors and separate the six classes (three damage classes) defined within the study area.

The fitness functions integrated in the GA reached classification accuracies of up to 94.8% when using forward selection models of the most stable genes featuring maximum 50 predictors. Based on those results, three from the original 27,417 predictors were extracted to map forest damages over the full image extent based on a support vector machines (SVMs) classification. We conducted the same experiment with 82 vegetation indices described in literature and achieved slightly lower GA overall accuracies of 86.8% using the nearest centroid classifier. The SVM maps produced with the three best VI predictors were comparable to the TAI results.

1. Introduction

Vegetation indices (VIs) are among the oldest tools applied in remote sensing studies. They have proven to be useful in the analysis of vegetation covers, e.g. through their near-linearly correlation with photosynthetically active radiation (PAR) or through their usefulness to estimate canopy attributes that are used in soil-vegetation-atmosphere transfer, surface energy balance, and global climate models (Glenn et al., 2008). Various studies dealing with vegetation indices have been published during the last 40 years. Different types of indices were developed over the years and were applied to a broad range of applications including the assessment of vegetation damages and stress (e.g. Vogelmann and Rock, 1988; Carter, 1994; Carter et al., 1998; Zarco-Tejada et al., 1999, 2002), chlorophyll content (e.g. Tucker, 1979; Datt, 1998; Gitelson et al., 2003; Zarco-Tejada et al., 2004), biomass (e.g. Rouse et al., 1973; Tucker, 1979; Zhang et al., 2009) and water content of plants (e.g. Tucker, 1979; Pefiuelas et al., 1993; Penuelas et al., 1997; Chen et al., 2005).

According to Bannari et al. (1995), there have been several attempts to structure the broad range of existing indices using criteria that varied from "integrated Landsat bands" (Lautenschlager and Perry, 1981), "number of bands" (Bariou et al., 1985), to the distinction between ratio indices and orthogonal indices (Huete, 1984, 1989). Bannari et al. (1995) propose to classify the existing indices into (1) first generation indices which embrace indices which are simply determined by empirical methods and (2) second generation indices which implement pre-knowledge and account e.g. for atmospheric or soil influences. Here, we propose to structure the existing VIs into four groups based on the mathematics applied to calculate the VI: (1) ratio and normalized difference indices, (2) ratio and normalized difference indices which incorporate correction factors, (3) derivative indices (red edge position techniques included) and (4) indices which calculate areas. The first group comprises the largest amount of broadband and narrowband indices described in the literature including those solely computing any kind of ratio or normalized difference between reflectance values at certain wavelengths. Well-known examples would be

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normalized difference vegetation index (NDVI) or the simple ratio index (SR) (Tucker, 1979). The second group consists of ratio indices that are extended by correction factors in order to take into account, e.g. the soil influences as it is common in the soil adjusted vegetation index (SAVI)-family (Huete, 1988). The third group sums up all narrowband vegetation indices which are calculated based on the 1st, 2nd or 3rd derivative of the spectral reflectance curve. The red edge position techniques (e.g. Filella and Penuelas, 1994) are a good example for such indices. The fourth group embraces integral-based indices which are indices calculating the area below a spectral reflectance curve and those calculating other areas as, e.g. the triangular vegetation index (TVI) proposed by Broge and Leblanc (2000). In this study a fifth group of vegetation indices is proposed: It bases on the idea of the TVI but instead of a triangle-area, the angles within the triangle are calculated. The concept of this approach has been presented earlier by Palacios-Orueta et al. (2006) who used a similar index to track moisture and to discriminate soil, vegetation and dry vegetation. In Khanna et al. (2007) the concept is further developed and the authors state that angular indices stand for an unexplored niche within optical remote sensing which are promising to determine ecologically significant parameters.

The use of remote sensing to detect forest damages induced by pollution, insects or climate has a long history starting in the 1970s. An overview on the assessment of different forms of damages in coniferous forests from satellite images can, e.g. be found in Ardö (1998). Regarding forest damages caused by insects a large number of remote sensing studies has been published in North America (e.g. Franklin et al., 2003; Skakun et al., 2003; Wulder et al., 2004, 2006). In this work the concept of angular indices was applied in a case study in the Bavarian National Park (BNP) in Germany, where one of the research themes focuses on the analysis of bark beetle (*Ips typographus* L.) infestations in unmanaged forested areas. Since 1988 the traditional forest inventory in the BNP was supplemented by aerial surveys. The gathered true color and color infrared (CIR) images were used to document the extent of the bark beetle calamities (Heurich et al., 2010). This approach to delineate dead wood and infested tree stands has been a time-consuming and costly task which was performed by manual photo interpretation. Heurich et al. (2010) proposed a new object-orientated semi-automatic approach. Object-orientated approaches account for the increasing availability of high spatial resolution imagery which provides information such as texture, shape and context that cannot be used by traditional per-pixel classification approaches which solely make use of the spectral information (de Kok et al., 1999; Blaschke and Strobel, 2001).

Besides the increased availability of high spatial resolution data, the access to high spectral resolution data has improved a lot within the last few years. Data with very high spectral resolution – hereafter referred to as imaging spectroscopy (IS) data, which is also known in the remote sensing community as hyperspectral data – has been successfully used in earlier studies to detect vegetation stress and damages. In forestry context most published precedents used IS data as basis for identification of stress-sensitive wavelengths (e.g. Ahern, 1988), development of stress-sensitive vegetation indices (e.g. Carter, 1994; Carter et al., 1998) and for integrating stress sensitive indices in more complex models (e.g. Zarco-Tejada et al., 2002; Coops et al., 2003; Pontius et al., 2008). Most of the developed indices make use of the reflectance in the visual (VIS) and near infrared (NIR) portion of the light and are often situated in wavelengths in which chlorophyll pigments or water absorb radiation. The sensitivity of these indices is therefore limited by the natural variability of the chlorophyll and water content of vegetation. The approaches proposed so far to detect damage classes within insect-infested forest stands have delivered diverse results and especially the pre-visual detection of insect-infested areas (green-attack stage) has been of limited success (Niemann and Visintini, 2005).

Here, 27,417 images representing the inner angles of 9139 triangles were calculated. These were shaped by all possible band combinations of 39 narrow band HyMap-channels in the vis–NIR spectral range (0.455–0.986 μm). The images served as inputs to an evolutionary genetic algorithm (GA) to detect the most stable predictors to separate 276 samples into 6 classes—three damage and three non-damage classes, which were defined based on visual interpretation of spatially highly resolved color infrared images (CIR). In general, high dimensional data such as IS data require advanced feature extraction or selection algorithms to handle the large – and partly redundant – information. GA represents a sound solution to select the best predictors from a huge number of input variables to solve a distinct classification problem. Kaufmann et al. (2010) give an extensive review on methodology options to process imaging spectroscopy data. After reviewing several search and extraction methods they stated that “implementing a genetic search algorithm for feature selection appears worthwhile”.

The main objectives of the study were:

(1) to evaluate the applicability of angular indices for the detection of bark beetle damages within a central European temperate forest ecosystem.
(2) to find the most suitable band combinations for the defined task, and
(3) to compare the performance of the best angular indices with those from 82 common VIs.

2. Materials

2.1. Study area and field data

The test site lies within the BNP at the border between Germany and the Czech Republic (49°3′19″N, 13°12′9″E). The area features rough terrain with elevations ranging between 600 and 1453 m. According to Heurich and Neufanger (2005) three major forest types dominate the vegetation: sub-alpine spruce forests with Norway Spruce (*Picea abies* (L.) Karst) mixed with some Mountain ash (*Sorbus aucuparia* L.) mainly found in high altitudes, the second group is dominantly located on slopes and consists of Norway spruce, White fir (*Abies alba* Mill.), European Beech (*Fagus sylvatica* L.) and Sycamore maple (*Acer pseudoplatanus* L.) while the third group resides in the valley bottoms and comprises Norway spruce, Mountain ash and birches (*Betula pendula* Roth, *Betula pubescens* Ehrh.). The size of the test site comprised an area of about 4.9 km × 7 km.

2.2. Remote sensing data

In August 2009 the HyEurope campaign organized by the German Aerospace Centre (DLR) collected airborne HyMap-data within the borders of the BNP. The image was recorded with an altitude of ca. 3200 m and a pixel size of 7 m. The solar zenith and the solar azimuth angles during the acquisition were 41.7° and 149.4°, respectively. The flight was heading from North to South with a slight shift resulting in a flight direction of 186.5°. The HyMap sensor produces imagery with 125 channels with wavelengths reaching from 0.45 to 2.48 μm. The spectral resolution lies between 13 and 17 nm depending on the wavelengths. Cocks et al. (1998) thoroughly address the HyMap sensor specifications. The scene was atmospherically and geometrically corrected by DLR using ATCOR4 model and ORTHO software. Consequently L2-data was delivered by the data provider. In addition to IS data, airborne digital CIR images featuring 0.4 m pixel size as well as true color composites