Remote Sensing of Environment 154 (2014) 192–201

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Object-based land cover mapping and comprehensive feature calculation for an automated derivation of urban structure types at block level

Michael Voltersen *, Christian Berger, Sören Hese, Christiane Schmullius

Department of Earth Observation, Institute of Geography, Friedrich-Schiller-University Jena, Loebdergraben 32, 07743 Jena, Germany

ARTICLE INFO

Article history:
Received 6 February 2014
Received in revised form 18 August 2014
Accepted 19 August 2014
Available online 16 September 2014

Keywords:
Urban areas
Object-based image analysis
Airborne
Land cover mapping
Urban structure types

ABSTRACT

Cities have evolved under manifold geographical, economical, historical, and cultural criteria, resulting in various sizes and shapes. Each city exhibits individual features and unique characteristics, despite that structural similarities appear. The separation into individual patterns, commonly named urban structure types (USTs), supports the characterization of physical, functional, and energetic factors of settlement structures, enabling associated environmental and socio-economic investigations as well as the comparison between the patterns of different cities. This study presents an automated approach for the classification of USTs based on remote sensing data in order to analyze the links between settlement structures and environmental issues, such as air pollution or urban heat islands, in a later stage of the project. Initially, an object-based classification routine is implemented to identify the land cover for the city of Berlin, utilizing spatially very high resolution aerial images and object height information. UST classes are defined based on the occurrence within the study area and are delimited by block boundaries. Afterwards, indicators for the derivation of USTs are generated based on the previously derived land cover information and the most valuable features are selected with the help of Random Forests. Finally, structural units are classified, involving common and new land cover based parameters. The focus is on the generation of an automated and transferable routine for a comprehensive UST classification covering the entire city. Comparing the results with reference data, good classification accuracies for both land cover and USTs indicate the suitability of the proposed method.

1. Introduction

Between one-third and one-half of the land surface has already been affected by humans (Vitousek, Mooney, Lubchenco, & Melillo, 1997). Hence, various changes in the ecosystem, e.g., modified energy exchange, altered hydrological regime, and increasing urban heat island (UHI) effect occur by replacing natural surface cover with man-made structures (Bridgman, Warner, & Dodson, 1995). Decision-makers and city planners need efficient methods for large-scale monitoring of urban areas in order to achieve sustainable urban growth. Consequently, it is important to understand the links between settlement structures and socio-economic as well as environmental issues (Pauleit & Duhme, 2000). The basis for this comprehension can be established by dividing cities into a variety of urban patterns, commonly named urban morphology types (UMT) (Gill et al., 2008), urban structural units (USU) (Osmond, 2011; Pauleit & Duhme, 1998), or urban structure types (UST) (Banzhaf & Höfer, 2008; Heiden et al., 2012; Wurm, Taubenböck & Dech, 2010). USTs describe the composition of a city with all its artificial and natural surfaces based on the assumption that settlements consist of distinct spatial units with similar building structures, open spaces, and land use forms composing delimitable patterns (Pauleit & Burkhardt, 2004). As a consequence, environmentally relevant issues like stormwater management, landscape planning, and urban heat island mitigation can be addressed holistically, improving the quality of life of city residents by understanding the link between urban microclimate and city structures (Erell, Pearlmutter, & Williamson, 2010; Osmond, 2011). Soil sealing and its consequences for the environment are said to be almost irreversible (Blum, 2013); for that reason a well-conceived city management on the basis of USTs becomes an important tool for urban planners. While research has intensively focused on subdividing distinct urban classes such as infrastructure or building types, the UST approach presents a comprehensive, consistent, and transferable classification framework for the total area of cities (Osmond, 2011).

UST classification for large urban areas is dependent upon remote sensing data and methods. The use of images acquired by airborne and spaceborne sensors offers a high degree of objectivity, transferability, and automation. Up-to-date consistent and extensive information about urban land use structures are provided. A few studies have already addressed the UST classification from remotely sensed data, showing differences in many respects.

* Corresponding author. Tel.: +49 3641 94 89 69; fax: +49 3641 94 88 82.
E-mail addresses: michael.voltersen@uni-jena.de (M. Voltersen), christian.berger@uni-jena.de (C. Berger), soeren.hese@uni-jena.de (S. Hese), c.schmullius@uni-jena.de (C. Schmullius).

http://dx.doi.org/10.1016/j.rse.2014.08.024

The classification depth varies between coarse class arrangements distinguishing only open spaces and three different intensities of built-up areas (Taubenböck, Esch, & Roth, 2006) and detailed class hierarchies of 15 or more classes (Banzhaf & Höfer, 2008; Gill et al., 2008; Hermosilla, Ruiz, Recio, & Balsa-Barreiro, 2012). Additionally, the boundaries delimiting homogeneous city blocks are either derived manually based on the evaluation of aerial photographs (Herold, Liu, & Clarke, 2003) or with the help of auxiliary data provided by municipalities or calculated from OpenStreetMap data (Bochow, Taubenböck, Segl, & Kaufmann, 2010). Likewise, the applied methods range from visual interpretation of aerial photographs (Gill et al., 2008) to the analysis of spatial metrics, image texture, and neighborhood graphs (Herold et al., 2003; Walde, Hese, Berger, & Schmullius, 2014). Related to that, the feature selection, a crucial step for a proper UST classification, exhibits major differences. On the one hand, features are selected based on the assumed characteristics of the previously defined typology of urban structures, underlying a subjective view (Banzhaf & Höfer, 2008; Lindner, Hese, Berger, & Schmullius, 2011; Wurm, Taubenböck, Roth & Dech, 2009). On the other hand, feature selection is performed utilizing statistical methods such as Random Forests or Sequential Forward Selection (Bochow et al., 2010; Walde et al., 2014). Furthermore, in most of the studies, the USTs of one city are analyzed whereas only some projects comprise a comparison of the transferability of the implemented methods to other region (Bochow et al., 2010; Puissant, Zhang, & Skupinski, 2012).

Examining the mentioned studies, some shortcomings become apparent. In many cases, the classification of city blocks is restricted to certain USTs, covering only parts of the city. As a consequence thereof, the classification depths prove to be insufficient. There is a lack of systematic extraction, calculation, and selection of suitable descriptive features for UST delineation. Descriptive features are often treated isolated, neglecting potential synergies of the combination of two or more parameters. In contrast, other studies need improvement regarding the achieved classification accuracies as well as strategies ensuring the transferability of the proposed methods in order to be qualified for operational applications. Considering the stated deficiencies, this study comprises an accurate object-based land cover classification, making use of multispectral data and height information, combined with an in-depth UST analysis. The detailed classification hierarchy contains several built-up classes as well as areas of natural surface cover, involving the entire area of the city. A comprehensive feature calculation of common parameters, landscape metrics, and rarely used features is performed. The most important features are selected knowledge-based and statistically with the help of Random Forests. Emphasis is put on an automated data processing in order to ensure the transferability of the methods, which will be tested for at least two other test sites in a further stage of the project. Finally, this study aims at the generation of highly accurate classification results compared to a reference map.

2. Materials

2.1. Study area

The city of Berlin is located in the north-east of Germany (52°31′ N, 13°24′ E). With more than 3.3 million inhabitants and an area of 891.7 km^2 it is the largest city and the capital of Germany (Destatis, 2013). Shaped by many historical events (e.g. industrialization, destruction during world war, separation into East and West Berlin) various structure types have evolved. Very densely developed areas can be found in the core area, featuring high amounts of impervious surface areas (ISA), whereas surrounding regions are characterized by large vegetation fractions. There is also an intensive variation of building types, even within the same block, and a great number of water bodies exist all over the city. The terrain features differences of 81 m in height.

2.2. Data basis

Multispectral raster data and height information were provided by DLR Berlin-Adlershof. The high spatial resolution airborne data was acquired by the UltraCamX sensor featuring 12 bit radiometric resolution with 1 m^2 pixel size. Four channels provide spectral characteristics in visible range and near infrared (Gruber, Ponticelli, Bernögger, & Leberl, 2008). Acquisition took place on September 23, 2010 during the morning hours. Thus, the small incidence angle of the sunlight causes major areas covered by shadows. Additionally, a digital surface model (DSM) computed by the stereoscopic interpretation of multiple overlapping UltraCamX scenes was also delivered by DLR Berlin-Adlershof, featuring the same high spatial resolution of 1 m pixel size.

Vector data was kindly provided by the Senate Department for Urban Development and the Environment Berlin (Senate Department for Urban Development & the Environment Berlin, 2010). Included block boundaries and information about manually derived urban structure types provide a basis for an automated UST delineation and serve as reference data for validation purposes.

3. Methods

The workflow of this study is subdivided into three parts: normalized digital surface model (nDSM) derivation, land cover mapping, and UST mapping. After the initial creation of an nDSM, a ruleset for land cover mapping is created and accuracy is assessed for each LC-class. Subsequently, land cover information is used to create descriptive features for all blocks within the study area. After designing a UST class hierarchy, a synergetic approach of knowledge-based and statistical feature selection is utilized in order to derive the defined urban structure types. Finally, an accuracy assessment of the generated UST map with the help of the reference dataset is connected.

3.1. nDSM derivation

Accurate land cover classification and UST mapping require area-wide height information. In order to generate object heights, an essential pre-processing step is the calculation of an nDSM. For this purpose, the Diff2Min approach has been developed using the Trimble eCognition software and its cognition network language (CNL) (Trimble, 2013). At first, a layer is created displaying the differences between the central pixel and the pixel with the lowest value of the DSM data within a moving window. A window size of 99 m edge length is chosen in order to take reference ground points of larger buildings or forested areas into account, but simultaneously preserving reasonable processing times. The resulting layer shows low values for every ground pixel and larger DSM-differences for elevated objects. A second layer is created containing only height information of the DSM for pixels with differences smaller than 1 m height in the first layer. This leads to a digital terrain model (DTM) with data gaps for elevated objects which are then filled by interpolation. Finally, after a slight smoothing of the DTM layer in order to remove edge effects, the nDSM is created by subtracting the values of the computed DTM from the given DSM. Accuracy of the generated nDSM is assessed for 250 randomly distributed reference points for elevated objects as well as ground pixels. A ground pixel is treated as correct if the nDSM value amounts to zero. The reference height of pixels of elevated objects is calculated by the difference between the measured DSM value of the respective pixel and adjacent ground pixels. Afterwards, deviations between heights of the reference points and the created nDSM are analyzed.

3.2. Land cover mapping

A detailed and accurate land cover mapping provides the basis for UST classifications. Errors in the derived land cover map are reflected in the accuracy of the USTs. The methodology presented in this paper