POTENTIAL OF HYPERSPECTRAL REMOTE SENSING DATA FOR THE AUTOMATED MAPPING AND MONITORING OF URBAN BIOTOPES

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ABSTRACT

Urban biotopes are an important subject matter for ecological urban planning. Area-wide mapping and monitoring of biotopes is based on visual interpretation of color-infrared aerial photographs and field investigations. This combined inventory yields a high level of detail and accuracy but, as a drawback, it is very time- and money-consuming. Thus, many municipalities take the effort to build up an initial biotope map, but not to make regular updates.

Hyperspectral data open up new opportunities for solving this problem. They allow a material-oriented identification of urban surfaces and vegetation types and the derivation of additional quantitative parameters (e.g. percentage of area, degree of surface sealing etc.). Since biotope types cannot be classified directly from pixels' grey values the idea of this study is to use a material-oriented classification to identify them. Therefore, biotope types are modelled by a set of quantitative parameters derived from classified hyperspectral images, e.g. the percentage of area of their constituent surfaces which could be vegetation types as well as man-made surfaces, open soil etc.. Building up a generally applicable model of biotope types that way, can also include parameters to describe the location and distribution of the constituent surfaces in the biotope. Once the model is build, it can be used to check urban biotopes, taken from existing biotope maps, for changes of their type with hyperspectral data. Only biotopes indicating a change have to be inspected in the field and updated manually if necessary.

The study is part of the Helmholtz-EOS project. Concept and methods of the study are presented focusing on the development of distinctive features for biotope types.

INTRODUCTION

Cities are centers of human activity. The intensive use of land in urban areas by housing, traffic or industrial areas leads to ecological impacts on the environment and to impacts on man's living quality as well. To reduce these impacts, municipalities attach great importance on ecological urban planning. Green spaces, for example, can serve several purposes: They are not only habitats for fauna, but can also be used as bio-indicators for pollution and do act as regulators of micro- and meso-climate (i).

Urban biotope maps are an important information source for ecological urban planning (ii, iii). They document the current state and quality of urban biotopes and are considered in landscape and town planning. Furthermore, they are accounted for in environmental impact assessments regulated in the German Environmental Impact Assessment Act (UVPG) and in the impact regulation, which is regulated in §§ 18,19 of the German Federal Nature Conservation Act (BNatSchG) and in §1 of the German Federal Building Code (BauGB).

Area-wide urban biotope maps are produced by visual interpretation of color-infrared photographs in combination with field investigations. Because this procedure is very time- and money-consuming many municipalities do not update their existing biotope maps regularly. Thus, there is a need for a time- and cost-efficient update system that takes in account the rapid changes in urban areas to ensure an adequate monitoring of urban biotopes.

DATA AND TEST SITE

For the development of an update system for biotope maps two types of input data are needed: An existing biotope map, which usually comes in vector format, and hyperspectral images. A list of urban biotope types contained in a biotope map is given in ii and iv. The hyperspectral images used in this study were collected by the HyMap sensor because it complies with the high spatial resolution requirement for urban analyses. The specifications of the HyMap sensor and of the four datasets used for the determination of the surface materials are shown in tables 1 and 2. The datasets all cover the same area in the city of Dresden, Germany.

Table 1: Technical specifications of the HyMap sensor

Sensor type	Airborne whiskbroom scanner
FOV	61.3°
IFOV	2.09 mrad
Scanning Frequency	6-24 Hz
No. of pixels (cross track)	512
No. of spectral bands	128
Radiometric resolution	16 bit
Spectral resolution	15-16 nm at 400-1800 nm
	20 nm at 1900-2500 nm
Spatial resolution	3-10 m

Table 2: Description of the HyMap datasets

	Date of acquisition	**Spatial resolution at nadir**
Dataset 1	19.05.1999	5.3 m
Dataset 2	01.08.2000	3.5 m
Dataset 3	20.07.2003	3.5 m
Dataset 4	07.07.2004	4.3 m

METHODS

Concept

The type of a biotope cannot be determined directly from the grey value of a pixel because a biotope usually consists of more than one surface material. To exemplify this: If a pixel is of the class “deciduous tree” it must not belong to the biotope type “deciduous forest”. Material-oriented maps of urban surfaces and vegetation types (v, vi) can be derived from hyperspectral images (subchapter “Data Preprocessing and Determination of Surface Materials”). For each pixel these maps contain the material fractions of each endmember. The idea of this study is to use these material maps to identify the biotopes of an existing biotope map. Therefore, by an overlay of the two kinds of input data numerical features, i.e. quantitative parameters will be derived to characterise the biotope types (Fig. 1). The numerical features are calculated for each biotope based on the material fractions of pixels that fall into the biotope. All developed features are calculated for all biotopes. The biotopes of each biotope type are analysed group by group to find features that show characteristic values to distinguish a biotope type from the others (“Feature Selection and Modelling” box in Fig. 1, specified in subchapter “Feature Selection and Modelling”). These distinctive features will be incorporated in a biotope type’s model. To account for the variations a biotope type could have, four different HyMap datasets are analysed in this procedure.

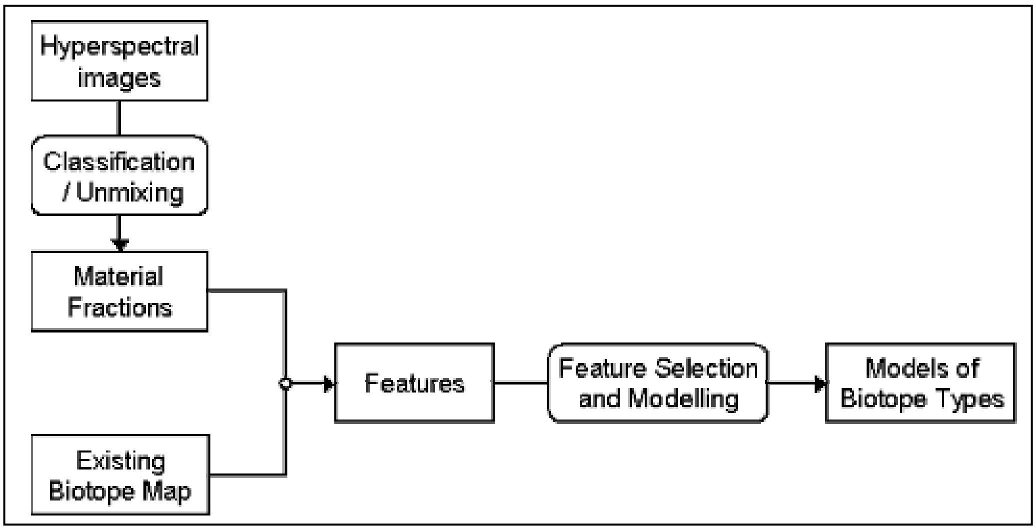

Figure 1: Generation of feature-based models to identify the type of biotopes from hyperspectral images

Data Preprocessing and Determination of Surface Materials

The atmospheric correction of the HyMap data was performed by MODTRAN-based software followed by an empirical line correction using field spectra. Geometric correction was done with a parametric geocoding approach. As described in the previous subchapter the modelling of biotope types is based on surface materials. The appropriate input data is produced by a classification and unmixing of the HyMap data. The fully automated processing chain consists of a feature-based endmember identification approach (vii), followed by a maximum likelihood classification with a very small threshold and an iterative linear spectral unmixing (v). The resulting image consists of n layers, one layer per surface class, which contain the fractions of endmembers per pixel as grey values. At present, 19 different roof materials, 4 fully sealed and 4 partial sealed pavement types, 2 bare ground types, 3 water types, 8 vegetation types and 2 types of shadow are implemented in the classification and unmixing process (vii).

Feature Development

The features belong to one of the five categories shown in Fig. 2.

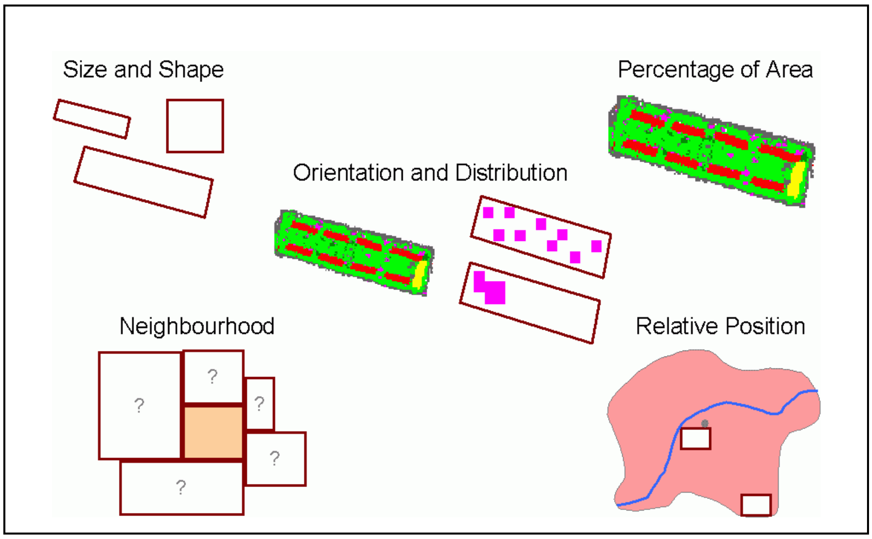

Figure 2: Feature categories

The feature categories of Fig. 2 can refer to different levels (Fig. 3). For example, the size and shape can be calculated for biotopes (biotope level) or for class segments in a biotope (class segment level). Percentage of area can be calculated for a single class in a biotope (class level) or for all pixels in a biotope. Orientation features apply to the class segments while distribution features can be used for classes and for class segments. Neighbourhood features can be calculated for biotopes or class segments. The relative position feature refers to the position of a biotope within the area of a city.

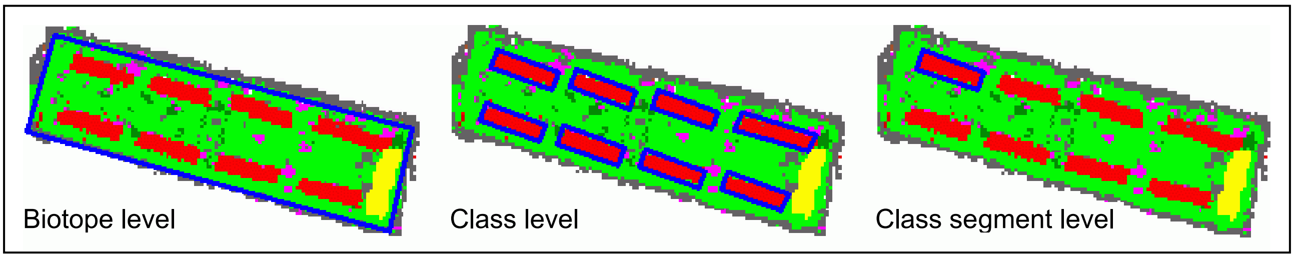

Figure 3: The figure shows a sample biotope. The objects to apply to the feature calculation are bordered in blue for each level. Class segments derived from endmember fractions by thresholding and clumping are displayed in different colours for each class (red and yellow: different roof materials; grey: asphalt; green: different types of vegetation).

Table 3 shows a complete list of the features that will be implemented. Many of the features are developed for specific cases, i.e. to identify one specific biotope type or distinguish a subtype from another. For example, the biotope features “Linear-Segment-Indicator” and “Long-Segment-Indicator” are developed to recognise streets and rows of trees. The “central or peripheral” class feature is developed to identify the perimeter block development, which is typical for many German cities. Applied to the roof material classes of a biotope high values will indicate a perimeter block development. The class segment feature “Orientation of principal axis” can identify another typical development style where big and longish buildings are build in a row divided by green spaces. The principal axes of those buildings should all point to the same direction and should lie on a straight line.

In contrast, other features like “percentage of area of classes” will help to distinguish the main biotope type classes from each other.

Table 3: Feature list

Level	**Category**	**Feature**	**Description**
Biotope	Size & shape	Area	Area of biotopes (A)
Biotope	Size & shape	Perimeter	Perimeter of biotopes (U)
Biotope	Size & shape	Degree of compactness	$C = (4\pi A)/U^2$ (normalized to 1 for a circle)
Biotope	Size & shape	Linear-Segment-Indicator	$LSI = \sqrt{EW_1}/\sqrt{EW_2}$ with the Eigenvalues EW_1 and EW_2 of the first and second principle component axes of a two dimensional object (e.g. biotope area)
Biotope	Size & shape	Long-Segment-Indicator	Skeletonization. Then longest way through the skeleton pixels.
Biotope	Neighbourhood	Biotope types in the neighbourhood	Types of adjacent biotopes or types of surrounding biotopes within a fixed radius
Biotope	Relative position	Position of the biotope within the city area	Distance of the biotope's centroid from the city's centroid normalized by the mean distance of the city's boundary pixels from the city's centroid
Biotope	% of area	Ratio pure pixels / mixed pixels	Ratio of pure pixels and mixed pixels in a biotope
Class	% of area	Percentage of area of classes	Percentage of area of classes in a biotope (class area / biotope area)
Class	Distribution	Central or peripheral	Mean distance of the class pixels from the skeleton of a biotope normalized by the mean distance of the boundary pixels from the skeleton of a biotope
Class	% of area	Mean pixel fraction	Mean pixel fraction of all pixels of a class in a biotope
Class	% of area	Ratio pure pixels / mixed pixels	Ratio of pure pixels and mixed pixels for a class in a biotope
Class	Distribution	Degree of compactness of a class after Newton's Universal Law of Gravitation	$G = \left(\sum_{n-1}^{i=1} \sum_{n}^{j=i+1} \frac{FiFj}{d_{i,j}^{2}} \right) \Big/ \left(\frac{n!}{2!(n-2)!} \right)$ with pixel fraction F of a class for all pixels n of a biotope with F > 0. And with the distance d between pixel i and pixel j.
Class segment	Size & shape	Area	Area of the segments of a class in biotope (A_s)
Class segment	Size & shape	Perimeter	Perimeter of the segments of a class in biotope (U_s)
Class segment	Size & shape	Degree of compactness of class segments	$C = (4\pi A_s)/U_s^{2}$ (normalized to 1 for a circle)
Class segment	Size & shape	Linear-Segment-Indicator	$LSI = \sqrt{EW_1}/\sqrt{EW_2}$ with the Eigenvalues EW_1 and EW_2 of the first and second principle component axes of a two dimensional object (e.g. class segment)
Class segment	Size & shape	Long-Segment-Indicator	Skeletonization of the segments. Then longest way through the skeleton pixels.
Class segment	Orientation	Orientation of principal axis	Direction of the first Eigenvector of the segments
Class segment	Distribution	Distances between class segments	Distances between the segments of a class in a biotope

Feature Selection and Modelling

It is obvious that a specific feature will not improve the identification of every biotope type. The challenge is to find the set of features that characterises a biotope type and to learn from training data the distribution of feature values. Then a model for every biotope type can be build consisting of the set of relevant features with corresponding membership functions and fuzzy logic rules to combine them.

At the beginning of this investigation the feature set of a biotope type will be selected manually. A feature will be included in the feature set if it helps to distinguish the biotope type from another one. This question can be answered by looking at the distribution of the feature values and by separability analyses with common distance measures like Bhattacharyya Distance, Transformed Divergence or Jeffrey-Matusita Distance using training data. The membership functions have to be designed manually looking at the training data as well. It is quite conceivable that the feature selection process could be automated in the future analogously to the feature selection process in vii.

Model Application

Once the biotope type models are build and trained they can be used with an older biotope map and a newer hyperspectral dataset to update the biotope map (Fig. 4). On every biotope the corresponding biotope type model is applied. Applying a biotope type model to a biotope means to calculate the selected features, to apply the membership functions on the feature values and to combine the resulting fuzzy values of the features based on fuzzy logic. This results in a single identity value for the biotope. Those biotopes with a low identity value are to be inspected in the field and updated manually in the biotope map. Checking and updating only those preselected biotopes will save much time compared to a complete update.

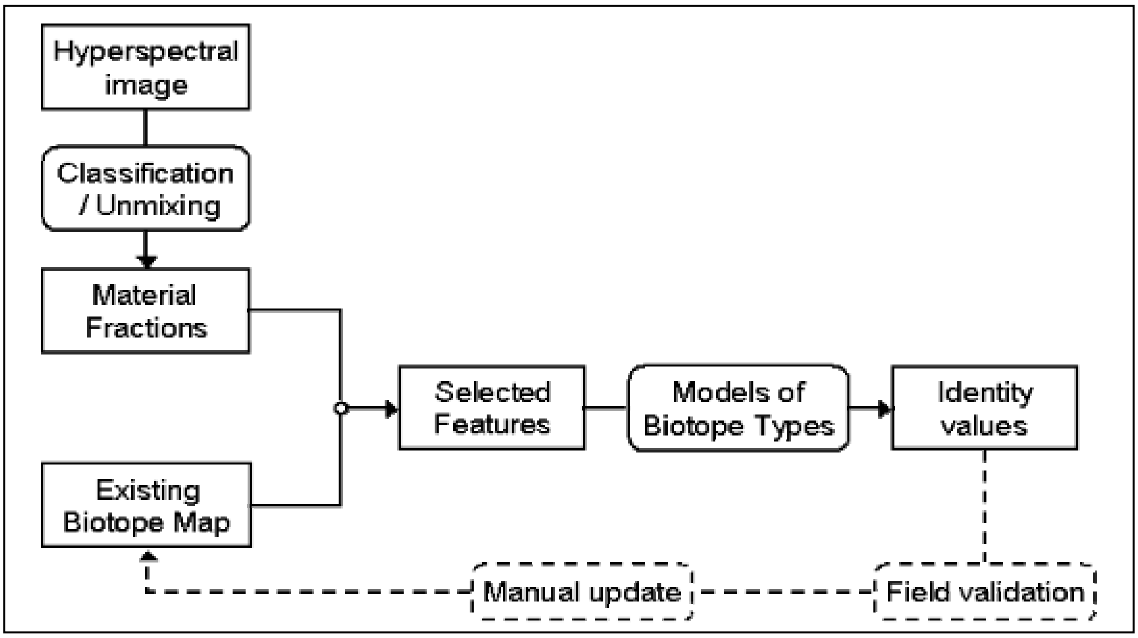

Figure 4: Update system for existing biotope maps. Solid: Automatic feature-based biotope identification system. Dashed: Manual validation and update

SUMMARY AND OUTLOOK

In this work the concept and methods for an update system for existing biotope maps have been presented. The core of the update system is an automatic feature-based identification system for biotopes. Present works concentrate on the development and implementation of features. First results for the modeling of selected biotope types are expected to be compassed in 6 month.

ACKNOWLEDGEMENTS

This work was made possible by several flight campaigns carried out by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) Oberpfaffenhofen, Germany. The biotope map was provided by the Umweltamt Dresden.

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