EXPLORING THE DEMANDS ON HYPERSPECTRAL DATA PRODUCTS FOR URBAN PLANNING: A CASE STUDY IN THE MUNICH REGION

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ABSTRACT:
Remote sensing can support municipal planning by providing thematic spatial information needed for decision making. The aim of the study is to explore the demands of municipalities to support their urban planning activities. A material map was derived from hyperspectral HyMap data of the Munich region using a linear spectral unmixing approach. Based on this land cover map several planning indicators were calculated. The products were discussed with planning departments of different municipalities. Cartographic presentation turned out to be an important aspect for the acceptance of the derived indicators. A promising application of the products is the communication with higher planning organizations, the mayor and city council. Advantages of using hyperspectral data products are more pronounced for the larger municipalities in the study area. Future steps should include further cooperation with those municipalities. Since municipal representatives expressed large interest in climate-related questions, further research should address the applicability of hyperspectral data for corresponding analyses.

KEYWORDS: Urban area; urban planning; HyMap; linear spectral unmixing

1. INTRODUCTION

The German government aims at sustainable urban development by reducing urban sprawl and the accompanied increase of impervious surface. Thereupon the German Ministry for Research and Education (BMBF) has initiated the research program REFINA which targets the development of approaches for both the monitoring of urban sprawl and the assessment of sustainable development in urban environments. The research presented here was carried out in this context. Remote sensing can support municipal planning by providing thematic spatial information needed for decision making. Depending on the information, large and frequent area coverage is possible as well as fast (automated) processing of the data.

Because the urban environment is very heterogeneous - many small objects along with a large variety of different materials -, a sensor with high spectral and spatial resolution is most suitable for mapping urban areas (Herold *et al.*, 2003). Therefore a hyperspectral HyMap data set served as a basis for this study.

The aim of the study is to explore the demands of municipalities on supporting their urban planning activities with additional geo-information. It is analyzed which products derived from hyperspectral data are needed to provide the municipalities with up-to-date information on the characteristics and sustainability of their development. To ensure the applicability of the provided products several municipal planners were involved in the definition and design of the methodology and final products. The partner was the 'Planungsverband Äußerer Wirtschaftsraum München' (PVM). This planning board supports the municipalities in the Munich region in their planning activities, such as the development of new zoning plans. Three representative municipalities which are supported by the PVM were selected as study sites. The heads of the construction department of the municipalities Unterhaching, Oberhaching and Strasslach-Dingharting took part in the workshops and discussions. Also the city of Munich was involved in the discussions. The participants of the city administration were from the department of regional planning and the department of health and environment.

2. STUDY AREA

The study area covers the city of Munich (Germany) and its rural outskirts (Figure 1). The recorded HyMap images cover the full range of urban densities and structural types, from the metropolitan Munich, through middle-sized cities to small villages in the rural outskirts. Munich is a metropolitan city with over 1.3 million inhabitants (Landeshauptstadt München, 2008). Unterhaching and Oberhaching are two small towns south of Munich with 22450 and 12570 inhabitants (www.unterhaching.de, www.oberhaching.de). Strasslach-Dingharting is a rural municipality with only 2700 inhabitants, 15 kilometers south of Munich (www.strasslach-dingharting.de).
For this paper two subsets are selected. The first subset is located in Munich, east from the city centre (marked with A in Figure 1). The second subset covers the town Oberhaching (marked with B in Figure 1). With these subsets an example of both an urban and rural built up area is provided.

3. DATA AND PRE-PROCESSING

Hyperspectral data of the study area was recorded with the HyMAP sensor in June 2007 (Cocks *et al.*, 1998) with a spatial resolution of 4 x 4 m. After radiometric correction the data was corrected for atmospheric influences and converted to reflectance with ATCOR (Richter & Schläpfer, 2002). Geo-referencing was done using ORTHO into the UTM WGS 84 coordinate system (Müller *et al.*, 2005). Additional to the hyperspectral images height data, building masks and maps of building blocks and parcels were used to calculate the planning indicators. Aerial photographs were used for validation purposes. All data were converted into UTM WGS 84 coordinates.

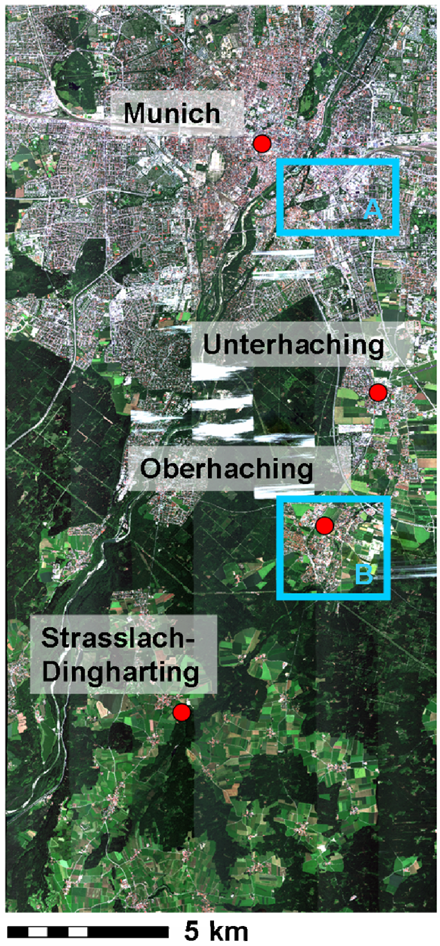

Figure 1: HyMap mosaic of the study area Munich, Germany (7 flight lines, true color)

4. METHODOLOGY

A land cover/land use map is a valuable source of information for urban planners. This is the first product that was derived from the hyperspectral data set. In cooperation with PVM and other REFINA project partners, a catalogue of requirements was defined. This catalogue represents a list of indicators which are relevant for urban land management. Also statistical indicators based on census data are included. For this study, five indicators were identified which can be derived from remote sensing data and which are relevant at the local planning level. These are building density, building volume, imperviousness, vegetation density and vegetation volume. They can be calculated based on the land cover map.

4.1 Data analysis

4.1.1 Land cover map

In order to derive a very detailed land cover map the underlying classification scheme focuses on the differentiation of single surface materials. For the identification of the materials the linear spectral unmixing approach described in Roessner *et al.* (2001) and Segl *et al.* (2003) is applied. To improve the separation between similar materials on buildings and non-build areas (such as roofing tiles and red loose chippings), a building mask derived from municipal vector data is used. The first step is to derive the image endmembers using a feature-based classification (Heiden *et al.*, 2008). With the endmember spectra, a maximum likelihood classification is carried out to find the pure pixels, called seedlings, in the image. The seedlings are the starting points for the actual unmixing. The mixed pixels are modelled by two endmembers. The tested endmember combinations are influenced by the neighbouring pixels: the pixel next to a roofing tile seedling is likely to have some abundance of roofing tile as well. The best mixture model is selected based on the root mean square error (RMSE). The spectral unmixing approach results in abundance maps for each class. For displaying purposes those maps are summarized in four products: dominant class, second class and abundance of both dominant and second class.

4.1.2 Indicators on urban environment

Table 1 lists the selected indicators and their definition. The parameters are calculated based on the material cover fractions in a reference area such as a building block.

Table 1: Selected planning indicators

Building density (%) = $\frac{abundance_{ROOF}}{area} * 100\%$
Imperviousness (%) = $\frac{abundance_{IMPERVIOUS}}{area} * 100\ \%$ IMPERVIOUS = $abundance_{ROOF}$ + $abundance_{FULLY\_SEALED}$ + $0.5 * abundance_{PARTIALLY\_SEALED}$
Building volume (m³/m²) = $\frac{\sum_{(i,j)_{AREA}} (abundance_{ROOF}(i,j) * height(i,j))}{area}$
Vegetation density (%) = $\frac{abundance_{VEGETATION}}{area} * 100\%$
Vegetation volume (m³/m²) = $\frac{\sum_{(i,j)_{AREA}} (abundance_{VEGETATION}(i,j) * height(i,j))}{area}$

4.2 Validation

In order to use the derived products in the planning process, it is very important to know how accurate they are. Therefore 14 building blocks in Munich are digitized and manually classified, based on aerial photos and field survey. An area-based validation is carried out for the cover fractions derived by the spectral unmixing. More details on the validation methodology can be found in Heldens *et al.* (2009). Moreover, for each of the validation building blocks the five selected indicators are calculated on the basis of the reference data and compared with the results derived from the hyperspectral images.

5. RESULTS

Figure 2 and Figure 3 present the unmixing results in the form of the dominant class for the subset of Munich and Oberhaching respectively. The legend of the land cover maps is shown in Figure 4. The average RMSE is 1.54 % for the Munich subset and 1.45 % for the Oberhaching subset. The area based validation of the abundances at building block level showed an average absolute abundance difference of 1.8% in comparison to the digitized reference blocks.

In Figure 5 the building density, imperviousness and building volume per building block are presented for the same subset of Munich. A comparison with the digitized reference building blocks showed that the parameters are accurate. The indicator imperviousness has an absolute average difference of 3.1% to the reference blocks. Of the five indicators the vegetation density has the largest absolute average difference of 8.3%.

Figure 2: Land cover map Munich (dominant class)

Figure 3: Land cover map of Oberhaching (dominant class)

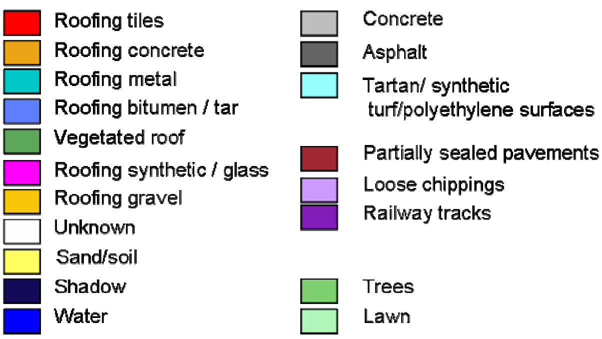

Figure 4: Legend to land cover maps

In Figure 6a the percent impervious surface per building block is shown for Oberhaching. During discussion of the results with the head of the construction department of Oberhaching it turned out that a smaller reference area was more suitable for the small town. Hence, the municipality provided a map showing the parcels and the parameters were calculated for these spatial units (Figure 6b).

6. DISCUSSION

In several workshops the products (material maps and indicator maps) have been discussed with the representatives of the different municipalities. One topic of discussion was the presentation of the products. Aspects such as smoothness, accuracy and spatial scale were claimed to be very important. Spatially, the derived land cover map is relatively coarse in comparison to the aerial images urban planners are used to work with. This decreased the acceptance of the data at first. Representatives of the city of Munich found the building block as reference area for the indicators very useful. For Unterhaching this would be acceptable as well. Oberhaching and Straßlach-Dingharting preferred information at parcel level.
The derived products are common indicators for the municipalities. However, except for the city of Munich none of the municipalities had the indicators available for their complete area before. Therefore the possible application of the derived products was an important topic during the workshops. The rural municipality of Strasslach-Dingharting has no strong demand on the information provided by the presented analysis. Because this municipality is so small, they have good knowledge about what is happening in their area.

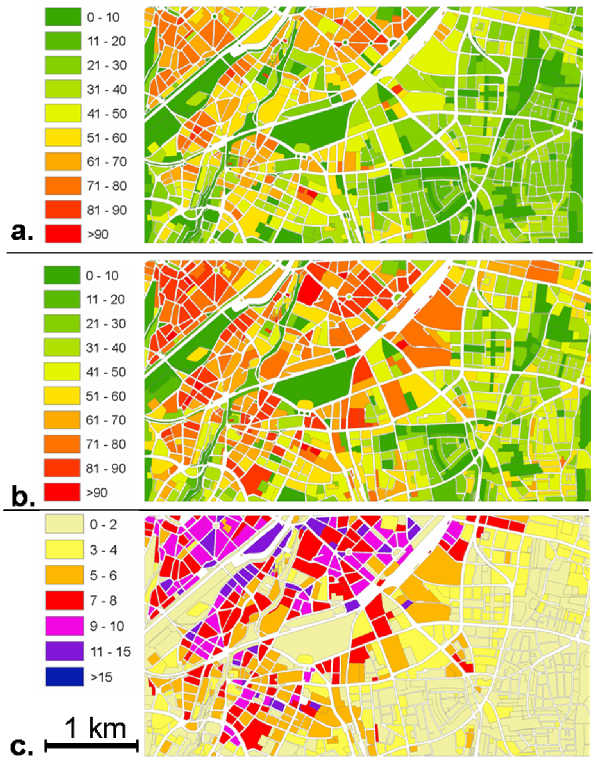

Figure 5: Indicators building density (a), percent impervious surface (b) and building volume (c) for the Munich subset.

Figure 6: Percent impervious surface for Oberhaching per building block (a) and per parcel (b).

The towns Oberhaching and Unterhaching see an advantage in the unbiased way of collecting the information. The products can be used to support policy making, for example in the communication of the planning department with the mayor and city council. Especially Unterhaching recognizes the advantage of using the derived products as a proof of their achievements on sustainable development, e.g. the reduced increase of impervious surface. The city of Munich already uses a variety of indicators for various purposes. They identified the possibility of a more efficient way of updating their maps as the main advantage of the presented approach. The representatives of the planning departments showed interest in further remote sensing products. Especially climate-related products, such as thermal images and information current or future locations of solar panels are desired.

7. CONCLUSION AND OUTLOOK

The different urbanization levels of the municipalities have strong influence on the requirements on the presented products, e.g. the most suitable mapping unit of the indicators. The cartographic presentation, such as the smoothness of the map, turned out to be important for the acceptance and use of the products. The disadvantages of using hyperspectral products from the municipalities' point of view are the high costs for acquiring the data and the need of a remote sensing expert for processing. However, hyperspectral data is seen as an interesting source of information with high potential. A helpful application of the products is the communication with superior planning organizations, the mayor and city council, for example to prove achievements in sustainable development. Especially the urban municipalities see advantages in the use of the offered products. With those municipalities a further cooperation is intended to explore the full potential of the hyperspectral data, e.g. by including the data into ongoing planning activities. Future research also comprises analysis of the possibilities of hyperspectral data to contribute to products for climate-related issues, because of the large interest expressed by the municipal representatives.

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