DETECTING URBAN BROWNFIELDS BY MEANS OF
HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT:

The international urban environmental partnerships focus on brownfields redevelopment, smart growth, sustainable transportation and land use, urban watershed management, green buildings, and solid waste recycling (U.S. Environmental Protection Agency = EPA - http://www.epa.gov/swerosps/bf/accomp2.htm). The emphasis of this project is a kick-off to detect this specific land use, i.e. brownfields, and by expanding upon object-oriented classification methods. On the global level brownfields first need to be characterized within their specific urban regions in different geographical latitudes and climates. Focussing on the local level brownfields sites in their certain urban environment can be described as a specifically defined class consisting of diverse objects that need to be characterized by their form, their position and their spatial context. As they may consist of different objects such as buildings, roads and vegetation an object-oriented classification approach is applied. The brownfields sites investigated upon are located in the City of Baltimore, Maryland, as EPA selected the City of Baltimore as one of 16 federal Brownfields Showcase Communities (http://www.epa.gov/brownfields/showcase.htm).

1. GOAL

1.1 Introduction

An interdisciplinary approach is essential for the successful regeneration of brownfield sites. A brownfield is a property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or con-taminant. It is estimated that there are more than 400,000 brownfields in the U.S. Cleaning up and reinvesting in these properties increases local tax bases, facilitates job growth, utilizes existing infrastructure, takes development pressures off of undeveloped, open land, and both improves and protects the environment. (http://www.epa.gov/brownfields/about.htm). Such deve-lopment embraces a wide range of issues including clean-up and economic redevelopment, legislation and the prominent roles of ownership and investment, the latter points being complicated by varying national, regional, or local approaches. Strong community participation is also involved.

The U.S. Environmental Protection Agency (EPA) is running a program to help states, tribes, communities, and other organizations to assess existing sites, prevent further contamination, safely clean up sites, and design plans to re-use brownfields. Abandoned industrial properties should be turned into thriving economic centers, useful recreational areas and beneficial open spaces. Once a source of jobs and economic benefits to the community, these properties frequently lie abandoned for fear of the contamination and the liability it implies (Howland, 2000). Through partnerships with OECD (Organization for Economic Cooperation and Development) member countries, EPA works to share best practices and national and sub-national environmental policies to help U.S. cities. As a consequence the Brownfields Land Recycling Program (http://phoenix.gov/BROWNFLD/brownfld.html#A) was initiated in the United States to stimulate reinvestment in one of the city's greatest assets: the available commercial land base in the inner city. The ecological advantages may be obvious to all, as the cleanup of urban brownfields reduces potential environmental hazards. But the benefits of reintegration of land into the economic cycle of the community need to be promoted strongly to take effect, as do the economic and social dimensions for the reinvigoration of cities.

Metropolitan areas underlie an enormously rapid change coming along with urban sprawl where new houses and commercial sites are being built at the fringe and the inner city is partly neglected with abandoned sites now left for redevelopment.

One of the objectives of the Brownfields Land Recycling Program was to create a Brownfields Sites Inventory database listing environmentally-impaired vacant and abandoned or under-used land. Program representatives have been working with various city departments and other governmental agencies in an attempt to develop this listing. Based upon the challenges associated with privately-owned properties and the limited resources available, compilation of an inventory has not been feasible for many communities (http://www.ci.phoenix.az.us/BROWNFLD/brownfld.html#A).

1.2 Aims

The emphasis of this project is to launch the detection of potential Brownfields sites and to provide this specific spatial data for communities. This goal is aiming high and also ambiguous as such resulting data are needed, however Brownfields do not only cover land but obviously are used land. The latter makes it extremely difficult to work on by means of remote sensing data as land use can only partially be assigned. Brownfields first need to be characterized within their specific urban regions in different geographical latitudes and climates with different ecological and economic situations. In their urban environment brownfields sites need to be characterized by their form, their position and their spatial context and can be described as consisting of different objects such as buildings, roads, and vegetation, and they can clearly be marked as a highly disturbed land use.

In order to work on urban brownfields two prerequisites are essential: a methodological approach that allows to classify complex objects combined with high quality data (see Barnsley, 1997).

1.3 Remote Sensing Data and Methodological Approach

For this study a panchromatic and multispectral Ikonos imagery acquired on 02-Oct-2001 is used (Space Imaging, LLC). Three overlapping flight paths were taken on the very same day to cover the entire City of Baltimore. In order to orthorectify the images the cubic convolution algorithm was applied.

The investigation presented in this paper expands upon an object oriented classification method as any multispectral classification scheme will fail to detect such a highly heterogenic object class. Image segmentation, fuzzy classification, and structure type assignment is performed by means of eCogniton software. This software follows a new, object oriented approach towards image analysis. The concept behind this software program is that important semantic information necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relationships. So first the image is being structured into user-defined homogeneous segments in any desired resolution, then the classification procedure can follow. The segmentation algorithm entails the simultaneous representation of image information on different scales. This procedure detects local contrasts and is especially designed to work with highly textured data, such as Ikonos, Quickbird, or digital orthophotos. The classification process is based on fuzzy logic, to allow the integration of a broad spectrum of different object features such as spectral values, shape, or texture. Utilizing not only image object attributes, but also the relationship between networked image objects, results in a classification scheme incorporating local context (Baatz et al., 2000). So land use classes can also be defined as "adjacent to" or "in a certain distance to"

another class. This fuzzy logic approach leads to the characterisition and description of distinct urban land use categories (Bauer & Steinnocher, 2001). The resulting information is integrated in a rule system on a higher level of image analysis on which classified land use objects are combined to semantic structure groups, in this case potential brownfield sites.

The assumption underlying this approach is that potential Brownfields sites are a land use type that follows a certain pattern (i.e. consisting of buildings, roads or road access, impervious surface and neglected green spaces) so that each object can first be classified and then be composed to a variation of structure groups).

1.4 Test Area

Brownfield sites presented in this paper will be taken from the City of Baltimore, Maryland. Baltimore has experienced a population decline by 11.5 % between 1990 and 2000 from about 736,000 to 650,000 inhabitants adverse to the development of the Baltimore Region which had an increase of 7.0 % during the same period of time from more than 2,3 million people to more than 2,5 million. Thus Baltimore City underlies an enormously rapid change resulting in urban sprawl and areas of conversion being located in rather central areas (http://www.baltimorecity.gov/government/planning/cens us/index.html).

EPA selected the City of Baltimore as one of 16 federal Brownfields Showcase Communities in 1998. This designation gives Baltimore preferred access to federal resources which help building up Brownfields incentives, and which initiate the Maryland Voluntary Cleanup Act in February 1997. Brownfields Showcase Communities have the following main goals: to promote environmental protection, economic redevelopment and community revitalization through the assessment, cleanup and sustainable reuse of brownfields, and, to link Federal, State, local and non-governmental action supporting community efforts to restore and reuse brownfields (http://www.epa.gov/swerosps/bf/showcase.htm).

An Ikonos data set exists for the whole county of "Baltimore City" (Maryland Department of Natural Resources - DNR) and there is abundant ancillary data available for the city online (http://www.dnr.state.md.us/gis/).

The Voluntary Cleanup Program (VCP) provides data on Brownfields properties for which the Maryland Department of the Environment (MDE) has received an application to participate in the VCP. It is this point data that is used here to derive surficial test sites for the classification scheme. Parcel boundaries are assigned to these properties by means of matching street addresses to each parcel. These data provide an excellent data base to develop the classification scheme (see Figure 1).

Figure 1. Brownfields sites in the southeast of Baltimore City near the Harbour. The yellow line shows the parcel boundaries.

2. CLASSIFICATION SCHEME

2.1 Image Pre-processing

Ikonos provides both, multispectral and panchromatic data with a spatial resolution of four and one meter respectively. Having the four multispectral bands with red, green, blue, and infrared at hand, the NDVI could be calculated for the image and stacked to the four bands as a synthetic fifth band. There is no necessity to perform an image data fusion because the software eCognition allows a multiresolution segmentation with the chosen bands weighted individually. Segmenting the image is an important prerequisite as it subdivides the image into a given number of separate regions. There is a high number of degrees of freedom which could be reduced to two degrees to obtain optimal objects for this classification scheme on urban Brownfields. These levels are connected in a hierarchical manner and represent image information in different levels simultaneously (Baatz et al., 2000).

2.2 Class Definition

Before classes are defined and the analysis should start it has to be clarified what the classification is aiming at. So the question has to be answered with which classes a Brownfields sites is expected to be described. The challenge of this study is to classify a land **use** type so it is tried to cut down the description of its use to its spatial appearance. The physical characteristics of the site may consist of different objects such as buildings (more or less rotten), impervious surface such as parking lots, roads and road access, and also sparse, neglected vegetation. When thinking about the information for a Brownfields taken from parking lots that are either intensely used, have few cars only, or are not used at all it is important to take into consideration which day of the week the image was acquired. It

is assumed that on a Brownfields site the parking lots are either empty or have few cars only. So if it was taken on a weekend, this information needed to be discarded. In this case the image information was gathered on a workday (Tuesday) later in the morning so it can be assumed that the amount of cars on an industrial or commercial parking lot represent some higher or lower intensity of business activities.

Although this definition is not unambiguous the necessity to find and describe parameters that sufficiently outline potential Brownfields sites by means of their surficial character is irrevocable.

The frame of the knowledge base for the classification is the class hierarchy which contains all classes of the classification scheme. On the higher level of segmentation the image was being classified into areas *with* and *without vegetation*. As Baltimore is located at the Patapsco River estuary, an arm of Chesapeake Bay with a large harbour area, *water* is a dominant class taken separately and not being subdivided.

On the lower level of segmentation meaningful classes were defined for the land use type of Brownfields and assigned to their super-objects *area without vegetation* and *area with vegetation*. The assignment to these 'super-objects' was as follows (see example given in Figure 2).

The class hierarchy of *area without vegetation* contains:
- Industrial / commercial building I (white roof)
- Industrial / commercial building II (black roof)
- Industrial / commercial building III (mixed roof structure)
- High intensity commercial / industrial area
- Paved parking lots - empty
- Paved parking lots - with few cars or cargo
- Paved parking lots - with many cars or cargo
- Bare soil

As the Ikonos imagery offers very high resolution even in the multispectral bands roof types needed to be differentiated which increased the number of classes without increasing the semantic contents and made the classification more complex than demanded. A gain in information is that number of cars and their density is easily seen which is an important issue in terms of the presumption for the surficial appearance of a Brownfields site.

The class hierarchy for *area with vegetation* contains:
- Residential area / single buildings
- Intermediate intensity commercial / industrial area
- Urban woodland
- Grass (lawn, park)
- Neglected green spaces

2.3 Class Description

To construct an elaborate knowledge base the best suiting features are taken to separate the target classes. The range of features goes from object features which include spectral image information, shape, texture, and hierarchy, to class-related features, i.e. relations to neighbour objects, sub- or super-objects, memberships and some more.

So parking lots can be classified by means of their spectral reflectance, and the amount of cars on a parking lot can be distinguished by its textural information (see Figure 2). Some classes also need to be characterised by their distance to a neighboring class, so if, for example, parks and some residential areas are difficult to distinguish, then the relative border to

water can help to assign the ambiguous object rather to the class *grass* than to *residential area*.
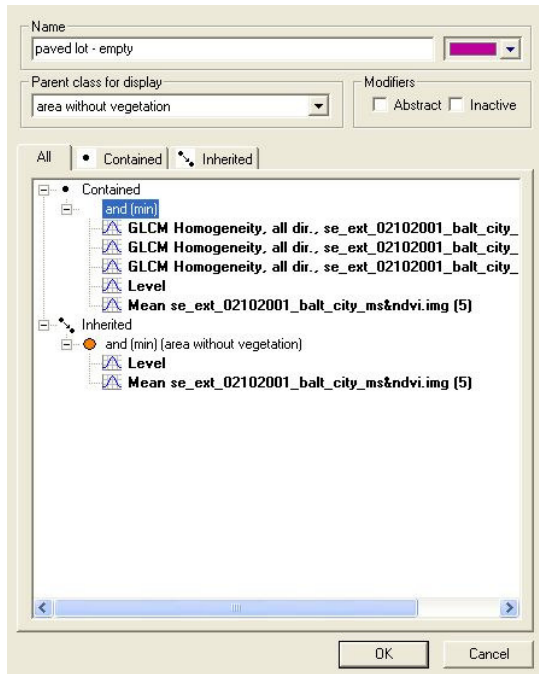

Figure 2. Class Description for parking lot – empty.

Figure 2 describes one class in the classification scheme. The class information *area without vegetation* is 'inherited' from the higher group level. The expert knowledge incorporates how a class is best described. It is shown that to assign the class *parking lot – empty* the mean value taken from band 5 (i.e. NDVI) is needed as well as textural information from several bands. Each feature encloses a membership function in which the threshold for the respective band or texture information is set-up by the user in a fuzzy range of values. The texture features evaluate the texture of the image object based on the gray level co-occurrence matrix (GLCM).

2.4 Fuzzy Logic Classification

Once all membership functions are set and the classes are defined in a best suited manner then each object is compared to each class description in the supervised classification. Its contained and inherited expressions produce membership values for each object and according to the highest membership value each object is then classified. If the membership value of an image object is lower than the predefined minimum membership value, the image object will remain unclassified. So technically speaking, a classification using a fuzzy rule base is done by finding out which combination of fuzzy features is suitable to distinguish one class from the others.

The classification does not produce brownfields sites as a resulting class, but delineates the above mentioned object classes. So the classification is an intermediate step towards the targeted land use detection. In the next and final step, certain classes are put together on a knowledge based rule to define potential brownfields sites as so-called structure groups.

Figure 3. Classified image sample showing large industrial buildings (in light and dark grey), various numbers of cars on parking lots (in red, purple, and pink), impervious surface without distinction (in white) grass (in bright green), neglected sparce vegetation (in olive green).

The classified image sample shown in Figure 3 shows the same subset as the Ikonos imagery in Figure 1 in order to visually follow-up on the procedure.

2.5 Structure Groups

So far the image objects follow the rule on which the image is segmented and the output classification underlies the same object pattern (see Johnsson, 1994). These segmented and classified image objects now need to be structured. Such objects of interest are knowledge-based and do not need to meet homogeneous standards. They are defined in structure groups which contain the criteria for a classification-based segmentation. All classes within one structure group are treated as fitting to each other, even if they represent very different class descriptions.

As mentioned in chapter 2.2 the potential brownfields sites are presumed to consist of various objects. Therefore not all objects of the resulting classification are taken to be structured into semantically more meaningful groups but only those needed to describe the very target group. So the structure groups for potential Brownfields sites follow a certain pattern. They are composed of the following objects but vary in their presence or absence. Examples of the criteria variations for potential target sites are given below:

Potential Brownfields sites I
- Industrial / commercial building
- Paved parking lots – empty
- Neglected green spaces

Potential Brownfields sites II

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- Industrial / commercial building
- Paved parking lots – few cars
- Neglected green spaces

Potential Brownfields sites III
- Industrial / commercial building
- Neglected green spaces

So several cycles are run to detect potential Brownfields sites as structured image objects. At this stage, structure groups without buildings have not been successfully assigned. It shows that Brownfields sites that are just covered with impervious surface are very difficult to be traced and the scheme has to be improved for this kind of surficial structure. The result is shown in Figure 4 with the same subset as the image and classified result above (see Figure. 1 and 3).

Figure 4. The black lines show correctly presented structure groups. The black outlined area including hatch marks just above the grouped brownfields marks where another brownfields site is located but cannot be detected with the presented method yet.

3. DISCUSSION

The land use classification of potential urban brownfields in the study region produces promising results. Using Ikonos imagery and working with an object-based classification approach, such as the software program eCognition provides, are essential tools to approach the investigation. There are a manifold factors that impact the classification and its individual steps including the timing of data acquisition (not only the phenological stage for green spaces, but also the day of the week for the presence of cars), the availability and quality of spatial test sites (point data such as street addresses are insufficient, parcel boundaries in terms of polygons are a prerequisite), and background information on the brownfields test sites (timing of cleanup and

possible redevelopment). Some of the more distinct classification errors are between shadow and dark roofs, residential areas and urban parks. Shadows are also an especially important consideration with the use of this high spatial resolution imagery, particularly shadowing of urban canopy into streets, alleys, and onto adjacent green spaces. As no multitemporal imagery is available for this particular study, the visual comparison with orthophotos or the knowledge of the urban structure helped to improve the first classification step (see Goetz, et al., 2003). To validate the assigned brownfields sites for the available test sites a visual check and image overlay can confirm. In order to improve the overall classification scheme and to validate the data for the whole city, ancillary GIS information such as data to urban green infrastructure, protected lands, private conservation properties, just to mention a few, need to be taken and compared with the resulting structure type. Investigations on potential urban brownfields sites by means of remote sensing data is a brand new field with no comparing projects. As the issue is compelling in many cities worldwide and high resolution imagery gain weight for urban problem solving it can be assumed that this issue is going to be tackled more often and that technical improvements for their detection will accelerate.

4. CONCLUSION

Brownfields sites have been recognized as important urban features that need to be detected in early stages, cleaned up, and redeveloped. Traditional approaches to mapping and monitoring these critical sites rely on ownership information, active neighbourhoods, realtors, to mention some, and are usually recorded as point data. This is not very practical for planning purposes, especially when the public issue goes beyond realtor interests and stand for healthy, vibrant neighborhoods. Landsat and ASTER data are simply not of sufficient spatial resolution (30m, 15m) to adequately map brownfields sites. So very high resolution imagery is needed to work in this field. The up-to-date pros and cons of the presented remote sensing approach are listed below.

Major advantages:
- Potential brownfields sites can be assigned for a whole city.
- Once a step-wise approach is worked out it can easily be modified for specific characteristics (e.g. Brownfields in a virtual city are most likely to be found next to water, or just below the local foothills, or they always consist of an older pavement than other lots do).
- Potentially assigned sites can be compared with available GIS data for a city.
- Verified sites can be marked in maps and checked by local authorities.

Major disadvantages:
- Remote sensing only offers a bird's eye perspective on a critical and challenging issue.
- Very high resolution data sets need to be available.
- There is no single assignment for such sites and their detection is highly knowledge-based.
- The detection is not operational yet and still part of basic research.
- Presently test sites or at least test areas are needed to verify or falsify Brownfields sites for a city.

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5.1 Copyright

5.2 Acknowledgements