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Development of a land use extraction expert system through morphological and spatial arrangement analysis

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ABSTRACT

Land use (LU) information is of significant value for various urban studies and is needed for a wide variety of decision-making initiatives in the range of global, regional and urban areas. A challenge that researchers and practitioners have been facing in urban modeling/planning is the lack of detailed information regarding how cities are structured and how urban development evolves. This study aims to develop a hierarchical rule-based LU extraction framework using geographic vector and remotely sensed (RS) data, in order to extract detailed subzonal LU information. The LU extraction system, which considers both morphological and spatial arrangement analyses at a fine spatial level – parcel, is developed to understand association/correlation rules between different urban features and their corresponding LU structures. In this study, structures and patterns of residential and commercial LUs are scrutinized. Residential and commercial LUs are first extracted by examining the morphological properties of individual parcels using a stepwise binary logistic models, which results in an overall accuracy of 97.5% and 92.4% respectively. A spatial arrangement analysis is then carried out through Gabriel Graph to identify structural patterns of residential and commercial parcels in order to cluster and separate them from other LUs. Extracting residential and commercial clusters helps to correct misclassifications arising from morphological analysis. The post-correction process results in improving the overall LU extraction accuracy by 1.6% for residential and 4.8% for commercial LU. The above exercises show that the LU classification framework developed can classify and then divide large zones with mixed LUs into single-LU subzones with a high accuracy.

1. Introduction

Land use (LU) information is of significant value for various urban studies and is needed for a wide variety of decision-making initiatives in the range of global, regional and urban areas. In the field of urban land use planning, one of the prime prerequisites for modeling and simulation of urban system involves evaluating existing land use patterns and mapping its changes over the time. In this regard, urban planners/modelers require different data, such as census population, employment, household, land use (developed and developing) to predict and simulate urban development. From the viewpoint of data collection, Nossin (1982) stated that "*The technical capability of data collection is the first step on a long road, but is often considered a goal in itself. It may be an objective in itself to create awareness of the steps that follow the data collection phase, so that it may serve the development purpose*". He also continued his opinion that "*data collection is the necessity of planning and is the fundamental of decision-making and developments*".

Many studies in the area of urban and transportation planning, such as Levinson and Yerra (2006), Abrahamsson and Lundqvist (1999), Crainic and Ricciardi (2009), and Flotterod and Bierlair (2011) have used land use information in their modeling, forecasting, classification, and predicting workflows. However, lack of detailed information on urban land use and of efficient gathering method have made modeling/planning of urban system difficult. Existing geographic and census data are usually dated and they cannot reflect rapid urban developments. This situation impels city planners/modelers to use zone-based system and aggregate LU information in the process. In this case, heterogeneity of urban LUs within the zones has to be tolerated, and economic activities are assumed homogeneously distributed over a zone. Subsequently, all activities within a zone are assumed to be located at the center of the zone — centroid. Popular transportation and land use models, such as Surface Transportation Efficiency Analysis

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Model (STEAM), TRANPLAN, PECAS, MEPLAN, TRANUS, ITLUPE, CUF-2, IRPUD, IRPUD2, and MUSSA, all follow such assumptions and therefore, their accuracy is deteriorated by the errors introduced by such a spatial aggregation. State-of-the-art urban planning and integrated land use and transportation modeling (ILUTM) demand up-to-date and much more detailed land and floorspace inventory data. Unfortunately, to date, there is no good way to obtain such data in an efficient and accurate way.

Remote sensing (RS) technologies have a great potential to extract detailed land use information. However, many barriers still exist and the technologies are far from practical for real-world applications in the urban and transportation planning/modeling, which will be discussed in Section 2. This paper proposes a hierarchical rule-based LU extraction system using geographic vector data and remotely sensed imagery. The two LU classes, including residential and commercial, are extracted through morphological and spatial arrangement analysis at a fine spatial level (i.e., parcel-level).

2. Study background

Distinguishing land use and land cover, which have been misunderstood by many, is important in understanding the scope of this study. Land cover classification is related to chemical and physical properties of landscape objects and usually describes features, which are visible on the ground such as buildings or trees. In contrast, land use is an abstract concept describing the amalgam of economic, social, and cultural factors (Barnsley and Barr, 1997) of a piece of land being used by human being. It should be noted that, unlike land cover, land use is defined in terms of function, such as residential, commercial, or industrial, rather than physical form. The abstract nature of LUs means that it is impossible to directly extract them from RS imagery (through traditional land cover classification method) because they are not physically visible. In other words, it is simply impossible to extract LUs based on grey values of RS images. Instead, LUs have to be inferred or generalized through various LU components (e.g., buildings vs. parking lots and their spatial relationship), for example, if a group of neighbor buildings are dense and the size of them are small, then the land being used is more likely for low-density residential purpose.

2.1. Review of land cover classification

Many studies have been dedicated to classify and extract landscape features (land covers) from remotely sensed images in either urban or suburban areas. Different techniques and course of actions have been used to tackle different situations from different types of aerial and satellite imagery (medium, high, and very high resolutions). It should be noted; however, the previous research of extracting land covers utilizing medium spatial resolution imagery, such as Landsat ETM+ and SPOT4, is only acceptable for the application of urban mapping at a very coarse level (Zhang, 1999, 2001; Mundia and Aniya, 2005; Deng et al, 2005).

However, such medium spatial resolution images are not useful for identifying detailed and accurate man-built urban features (such as buildings, streets, and parking lots), which is the need of the present research. This is mainly due to the lower spatial resolution of such images on one side and the complexity of urban features on the other side (Beykaei et al., 2010). Therefore, there is a need to incorporate very high resolution (VHR) imagery along with spatial information for extracting detailed LU information in an urban area. Many other studies (Xiao et al., 2004; Liu and Prinet, 2005; Pacifici et al., 2007; Mohaptra and Wu, 2008) have also shown the great potential of VHR imagery in detecting detailed urban features. However, the disadvantage of using such images is their limited spectral information (usually 3 or 4 bands), which makes classifying land covers with similar spectral signature difficult.

2.2. Review of land use classification

On the other hand, LU classification, particularly in urban areas, exhibits some unique features that make the related research even more challenging. The previous studies show that extracting LU information is the most challenging part of classification process and it needs other auxiliary data and a significant post-classification analysis. Mesev (2005) mentioned that due to abstract nature of LUs, extracting detailed LU information inevitably relies on auxiliary geographic or spatial data (non-spectral data) as well as images (spectral data) to improve the accuracy of classification. This is because that LU is defined based on its function, rather than its physical or chemical properties. The function of a LU cannot be directly observed, but need to be generalized and inferred through its various components, such as building size, the quantity of parking and vegetation area. In this regard, a far less number of studies have been devoted to extracting urban LU information via remotely sensed imagery. Consequently, the techniques being developed for land cover classification and applied to some well-known classification software, such as ENVI and eCognition, have not been proven to be useful in LU extraction.

Bales et al. (2008) used partial morphological reconstruction to better preserve the shape of objects, which contains the information about the minimum and maximum dimension of urban objects, to improve the classification results. Barnsely et al. (2003) used Light Detection And Ranging (LiDAR) and multi-spectral image data to determine urban LUs through an analysis of the spatial composition of building. Three morphological properties of building including roof area, compactness and height, were examined in their study. Yoshida and Omae (2005) studied the form and structure of urban features in Tokyo based on their urban landscape model (ULM) using RS data to extract residential and industrial areas. They used city blocks (spaces between street grids) as the analysis unit. The interrelationships as well as geographical distribution of blocks were interpreted based on their morphological properties. In this regard, they concluded that the correlation and interrelation of the parameters (morphological properties) are important to extract LU information from images. The two questions arise from their study: (i) *what combination of properties and relations provides the best separation of the two land use categories, and* (ii) *is this sufficient to identify areas of each land use unambiguously?* Despite the fact that the above studies attempted to improve LU classification in different fashions, only limited enhancements have been achieved. Further, no one has really answered the two above questions raised by Pesaresi and Bianchin (2001) ten years ago and no solid and effective method has been materialized.

Overall, the literature demonstrates that the application of remote sensing technology in the urban and transportation planning/modeling is indisputable and promising, but it is still immature for real-world planning applications, especially for extracting detailed LU information in urban areas. Studies in this area are usually contributed from two disciplines: Geodesy and Geomatics Engineering and Civil Engineering. From the viewpoint of geodesy and geomatics engineers, extracting precise land cover information from remotely sensed imagery is the priority whereas less attention has been paid to their applicability to other disciplines such as urban and transportation planning or modeling. From the viewpoint of planners, land use information is more important than land cover in their modeling and forecasting workflow to which few studies have been dedicated.