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A hierarchical rule-based land use extraction system using geographic and remotely sensed data: A case study for residential uses

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ABSTRACT

Lack of detailed land use (LU) information and of efficient data gathering methods have made modeling of urban systems difficult. This study aims to develop a hierarchical rule-based LU extraction system using very high resolution (VHR) remotely sensed imagery and geographic vector data. Land cover information extracted from remote sensing and several types of geographic data from the study area, City of Fredericton, Canada, are fused into a comprehensive database, in order to develop a sophisticated LU Extraction Expert System (LUEES). This paper illustrates how the proposed LUEES though a case study for residential uses in the study area. Morphological (individual-based) analysis at the building-level is carried out through a step-wise binary logistic regression model, which differentiates residential and non-residential buildings and results in an overall accuracy of 93.1%. The results derived from morphological analysis are then subject to a post-correction process using a spatial arrangement analysis, in order to further mitigate the misclassification issues arising from the morphological analysis. In this regard, Gabriel Graph connectivity examines the spatial structure and arrangements of urban features concerning different LU types. It is found that the spatial arrangement analysis further enhances the residential LU classification accuracy, which gives rise to an overall accuracy of 97.4%. It is believed that, equipped with such a powerful LU data collection tool and resulting detailed/accurate LU data, urban planners/modelers should be able to more reliably and precisely represent/predict economic interactions, activity locations, space and housing developments, business expansion, and trip patterns.

1. Introduction

Land use (LU) information is important for urban and transportation planners to understand spatial orientation of existing activities and to forecast urban changes or trends of development over the space–time continuum. Land use is an abstract

Abbreviations: BLM, binary logistic model; CA, census agglomeration; CBD, central business district; CSD, census subdivision; DB, dissemination block; DPM, Digital Property Map; FAR, floorspace area ratio; GIS, geographic information system; LIDAR, light detection and ranging; LUEES, Land Use Extraction Expert System; non-Res, non-residential class; Res, residential class; RGB, Red–Green–Blue; ULM, urban landscape model; VHR, very high resolution.

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concept describing the amalgam of economic, social, and cultural factors (Barnsley and Barr, 1997) of a piece of land being used by human beings. Land use is defined in terms of the function of a piece of land, such as residential, commercial, or industrial. Lack of detailed land use information has forced city planners and modelers to use large aggregated zones in their models, and consequently accept undesirable approximations and errors in their analyses and planning workflow. This problem persists because of lacking of decent and periodic land use surveys. The reason is simple: traditional ground surveys are time-consuming, labor-intensive, error-prone, and costly to carry out. Currently, LU surveys are mainly achieved through ground surveys or visual interpretations of aerial or satellite imagery. Consequently, as an alternative, planners/modelers often have to synthesize LU data from different sources (e.g., GIS and census) to provide a good indication of the system. Due to the limitation described above, many operational land use transportation models, such as PECAS (Hunt and Abraham, 2005), MEPLAN (Abraham, 1998), TRUNUS (De la Barra, 2005), ITLUP (Putman, 1995), and MUSSA (Martinez, 1996), were developed upon aggregated LU data.

However, urban planning and especially integrated LU and transportation modeling process require up-to-date and detailed land and floorspace inventory data. Unfortunately, there is no traditional way to collect such data quickly and efficiently. Therefore, it is highly desirable to develop a tool to assist planners to collect such data in a quick, efficient, reliable and non-intrusive way. In this regard, remote sensing provides fast and efficient ways for monitoring urban LUs and it is growing as a promising tool to extract/update detailed LU information. It offers a great potential for enhancing current urban planning processes.

This paper proposes a hierarchical rule-based LU extraction system using geographic vector data and remotely sensed imagery. A case study with a special interest on extracting subzonal residential uses is presented here to demonstrate its utility. Morphological analysis examines building properties derived from geographic vector and RS data in order to recognize LU patterns. A binary logistic model is fitted to the data to classify residential vs. non-residential buildings. Afterwards, spatial pattern of building arrangement is studied in order to implement a post-correction process. It should be noted that this study is different than previous studies because it dedicates to detailed land use extraction and their spatial arrangement analysis.

The rest of this research is organized as follows: Section 2 provides a literature review to the previous studies in the areas of land cover and land use classification. Section 3 describes the study area, remote sensing (RS) imagery and geographic data used in this study. The proposed solution and methodology using morphological and spatial arrangement analysis are explained in Section 4. In Section 5, the developed LU classification system is evaluated in order to examine its capability in extracting residential LU. Finally, Section 6 presents the conclusions, recommendations, and future research directions of this study.

2. Literature review

Many studies have been dedicated to classify and extract landscape features (land covers) from remotely sensed images in either urban or suburban areas. It is found that the low and medium resolution imagery are not useful for identifying detailed man-built urban features which is the target of the present research, such as building, street, and parking lots (Deng et al., 2005; Mundia and Aniya, 2005; Zhang, 1999, 2001). This is due to the lower spatial resolution of such images (Beykaei et al., 2010). Therefore, there is a need to incorporate very high resolution (VHR) imageries and spatial information for LU classification purpose in urban areas. Chan et al. (2009) mentioned that "...*it seems the choice for extracting land uses in urban areas is VHR satellite images*".

LU classification, particularly in urban areas, exhibits some unique features that make the related research even more challenging. The previous studies (Beykaei et al., 2011, 2012, 2013) show that extracting LU information is the most challenging part of the classification process and it needs other auxiliary data and significant post-classification analysis. Mesev (2005) mentioned that LU classification inevitably relies on auxiliary GIS data (non-spectral data) as well as images (spectral data) to improve the results due to its abstract nature. This is because LU type is defined based on its function (residential, commercial, industrial, etc.), rather than its physical or chemical properties (color, size, material, etc.). The function of a LU cannot be directly observed and requires to be generalized through its various components, such as building size, the quantity of parking space and vegetation area. In this regard, limited numbers of studies have been devoted to extracting urban LU information via remotely sensed imageries. Consequently, the techniques developed for land cover classifications which are currently used in well-known classification software, such as Envi and eCognition, have not been proven to be useful for LU extraction purposes.

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, therefore enhancing the classification results. Barnsley et al. (2003) used LIDAR and multispectral image data to determine urban land uses through an analysis of the spatial compositions of buildings. Three morphological properties of a building, namely 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. They used city blocks (spaces between street grids) as their spatial study 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.