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ES4LUCC: A GIS-tool for remotely monitoring landscape dynamics

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ABSTRACT

Given the potential impacts of land cover changes on surface processes, accurate mapping of landscape dynamics is a crucial task in environmental monitoring. The use of commercial software for remote sensing of landscape changes requires appropriate expertise in sensor technology and computing resources that are not always available to decision makers. This paper presents the development of an experimental prototype of a lightweight and user-friendly GIS tool – ES4LUCC – a semiautomatic software for change detection and classification of land use/cover. The tool is based on image processing techniques applied on multi-temporal remotely sensed spectral and surface model data. The GIS-based tiling approach allows to non-specialists of remote sensing to manage high-dimensional data even from low performance computing platforms. The paper synthesizes the implemented digital image processing that form the basis of ES4LUCC, including data correction, classification and change detection, map refinements. It also describes the software architecture, the main IDL modules and the integration with GIS through a tight coupling approach and.dll calling functions. The main modelling process is controlled through a powerful GUI developed as part of the ArcMap component of ESRI ArcGIS. The software is tested by using bi-temporal color-infrared ADS40 and Light detection and ranging data acquired on a 80-km transect of the Marecchia river (Italy). The outputs of ES4LUCC give an understanding of the natural- and human-induced surface processes, such as urban planning, agricultural and forest practices, fluvial dynamics and slope instability. The model provides reliable maps (90.77% overall classification accuracy) that represent useful layers for environmental landscape management.

1. Introduction

Land use/cover change (LUCC) represents a basic synoptic footprint of occurring natural- and human-induced processes on the Earth surface including biogeochemical cycling (Penner, 1994), erosion of soils (Douglas, 1999), urbanization (Carlson and Arthur, 2000), and is expected to be the most significant variable for the next decades impacting on the environment (Chapin et al., 2000). The significance of providing accurate maps of landscape-scale land use/cover changes is emphasized by their potential impacts on surface processes and related natural hazards (landslides, floods) and socio-economic aspects (urban and natural resource planning) (e.g., Beguerìa, 2006; Forzieri and Catani, 2011; Kundzewicz et al., 2005). Despite environmental protection strategies led many institutions responsible for land use management/regulation to enhance systems for landscape monitoring (Krausmann et al., 2003; Randolph, 2004), low performance computing platforms and limited know-how in sensor technology represent possible constraints for decision makers.

Synergies of remote sensing and Geographical Information Systems (GIS) have been demonstrated to be very powerful tools enabling a wide range of users to easily deal with complex multi-task environmental monitoring issues (e.g., Forzieri et al., 2008; Shalaby and Tateishi, 2007; Skidmore, 2002). A large body of literature proves the great potential of remote sensors (air- and space-born) to describe the spatiotemporal variability of land use/cover changes (e.g., Coppin et al., 2004; Radke et al., 2005). Standard remote sensing change detection methods can be essentially divided into pre-classification and post-classification techniques (Yuan et al., 1998). Pre-classification techniques focus on the use of various algorithms, such as principal component and vegetation indices, directly to the multi-temporal data stack, to generate “change” vs. “no-change” maps. Noteworthy are the recent works of Kennedy et al. (2010) and Cohen et al. (2010) which developed an image times series analysis to identify possible short and long term trends of land cover changes. Pre-classification methods showed high capabilities to capture temporal trajectories of land surface variations, but do not provide information on the nature of change itself (e.g., Ridd and Liu, 1998; Singh, 1989). Post-classification methods use separate classifications of images acquired at different times to produce change maps

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by comparison of the obtained single-image classification (Mas, 1999; Jensen, 2004). The accuracy of the change maps is inevitably dependent on the accuracy of the individual classification and is subjected to error propagation (e.g., Yuan et al., 2005). Despite that, the afore-mentioned methods have showed encouraging performances, both techniques assume appropriate operator expertise in remote sensing and adequate computing resources – especially for high-dimensional data – that are not always available for operational-stage implementations. Expert systems – by basing on a priori knowledge through predefined rules with multiple data sets and management options – represent valuable alternatives to cope with the afore mentioned problems and to model landscape (e.g., Zhou et al., 2009; Aitkenhead and Aalders, 2011). In this context, Geographical Information Systems (GIS) are useful devices for handling spatial data, performing distributed analysis and manipulating input/output through user-friendly graphical user interfaces. Commercial software (e.g., eCognition, ERDAS, ENVI) powerfully link remote sensing and GIS platform, even if a sufficient training and experience are always required to run these packages. Considering the performed enhancements in remote sensing approaches for change detection analysis (e.g., Lu et al., 2004), there is a great need of more progress in development of lightweight GIS-based tools to assist in remote sensing monitoring of LUCC allowing non-specialists to satisfy their specific needs.

This paper presents the development of an experimental version of a remote sensing/GIS-based software for mapping land use/cover changes (LUCC): the expert system for land use/cover changes (ES4LUCC). Classification and change detection algorithms are based on temporal variations of multispectral and digital surface model data, are coded in ENVI IDL and encapsulated into an efficient ESRI ArcGIS-based tool. The approach was tested on a large imagery dataset, including multispectral ADS40 and Light Detection and Ranging data, of the Valley of the Marecchia river (Italy), currently undergoing rapid land cover dynamics. The main novel contribution of this paper consists in the implementation of a set of digital image processing techniques in a single GIS tool allowing to non-specialist to process high-dimensional data for mapping purposes from low performance computing workstations. ES4LUCC requires ArcGIS Desktop 9.3 (Spatial Analyst and 3D Analyst), ENVI 4.7 and IDL Virtual Machine.

The implemented remote sensing approaches for change detection and classification analysis are described in Section 2, while software development is explained in Section 3. Section 4 shows the application of ES4LUCC to the study area and Section 5 summarizes the main findings of this work.

2. Digital image processing

Classification and change detection analysis of ES4LUCC are based on a semiautomatic procedure that exploits the synergies of multi-temporal/multi-source remote sensing data and GIS functionalities. Bi-temporal multispectral data and digital surface models are needed as inputs. Detection of land use/cover changes (LUCC) focuses on temporal variations of remote sensing data by discriminating: devegetation (DV), revegetation (RV), urbanization (UB), demolition (DL), landslide (LS) and river bed transitions (ORV, NRB, old and new river bed, respectively). Additional permanent land use/land cover classes (LULC) have been identified: forest (FS), shrub (SH), grass (GS), bare soil (BS), building (BL) and permanent water (PW). The methodology for monitoring landscape dynamics consists of three main modules written in Interactive Data Language (IDL, Research System Inc.): (1) data pre-processing (DPP); (2) multi-temporal decision tree classifier (MTTDC_CLASS); and (3) morphological image analysis (MTTDC_MORPH), (Fig. 1). In the following paragraphs the three steps are described in details.

2.1. Data pre-processing (DPP)

Geo-referenced multispectral images are atmospherically corrected through the ENVI QUAC module (Research System Inc). Then, the available multi-source remote sensing data is resampled to a common spatial resolution corresponding to the finest available input data. Derived features are generated for each observation time from the resulting dataset including the normalized difference vegetation index (*NDVI*, Tucker, 1979) and normalized digital surface model (*nDSM*).

The *NDVI* has been widely employed using remote sensing multispectral data to monitor plant growth (vigor), vegetation

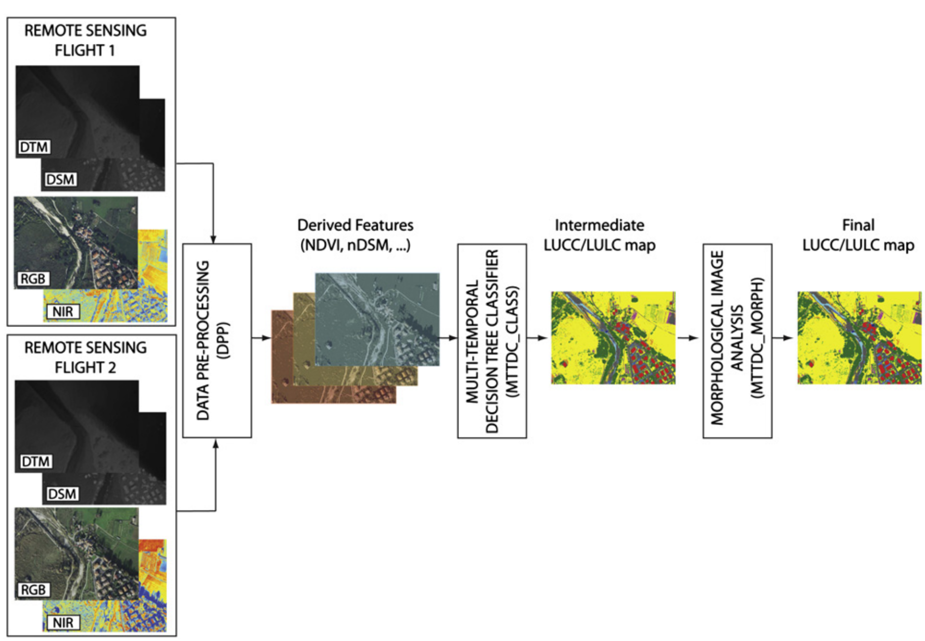

Fig. 1. Flowchart of the proposed remote sensing image processing for change detection/classification purposes.