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Urban mapping, accuracy, & image classification: A comparison of multiple approaches in Tsukuba City, Japan

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A B S T R A C T

The rapid growth of urban space and its environmental challenges require precise mapping techniques to represent complex earth surface features more accurately. In this study, we examined four mapping approaches (unsupervised, supervised, fuzzy supervised and GIS post-processing) using Advanced Land Observing Satellite images to predict urban land use and land cover of Tsukuba city in Japan. Intensive fieldwork was conducted to collect ground truth data. A random stratified sampling method was chosen to generate geographic reference data for each map to assess the accuracy. The accuracies of the maps were measured, producing error matrices and Kappa indices. The GIS post-processing approach proposed in this research improved the mapping results, showing the highest overall accuracy of 89.33% as compared to other approaches. The fuzzy supervised approach yielded a better accuracy (87.67%) than the supervised and unsupervised approaches. The fuzzy supervised approach effectively dealt with the heterogeneous surface features in residential areas. This paper presents the strengths of the mapping approaches and the potentials of the sensor for mapping urban areas, which may help urban planners monitor and interpret complex urban characteristics.

Introduction

Most of the world population currently lives in urban areas. The worldwide urban population is estimated to be 3.3 billion and is predicted to almost double by 2050 (United Nation, 2008). Persistent dynamic urban change processes, especially the remarkable worldwide expansion of urban populations and urbanized areas, affect natural and human systems at all geographic scales, and are expected to accelerate in the next several decades (Miller & Small, 2003). Worsening conditions of crowding, housing shortages, insufficient infrastructure, and increasing urban climatological and ecological problems require consistent monitoring of urban regions.

Recent advances in remote sensing technologies and the increasing availability of high resolution earth observation satellite data provide great potential for acquiring detailed spatial information to identify and monitor a number of environmental problems of urban regions at desirable spatiotemporal scales (Carlson, 2003; Miller & Small, 2003). Transitions in architecture and building density, vegetation and intensive socioeconomic activities at the block level in cities often transform the urban landscape towards heterogeneity (Cadenasso, Pickett, & Schwarz, 2007). Therefore, the urban environment represents one of the most challenging areas for remote sensing analysis due to the high spatial and spectral diversity of surface materials (Herold, Scepan, & Clarke, 2002; Maktav, Erbek, & Jurgens, 2005). In recent years, a series of earth

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observation satellites have provided abundant data at high resolutions (0.6–2.5 m; QuickBird, IKONOS, OrbitView, SPOT and ALOS) to moderate resolutions (15–30 m; ASTER, IRS and LANDSAT) for urban area mapping. Remote sensing data from these satellites have specific potential for detailed and accurate mapping of urban areas at different spatiotemporal scales. The high resolution imagery provides data for monitoring urban infrastructures, whereas moderate resolution imagery can provide synoptic measures of urban growth, surface temperature and more. A wide range of urban remote sensing applications from both sensors is available to date (Carlson & Arthur, 2000; Gatrell & Jensen, 2008; Maktav et al., 2005; Miller & Small, 2003). These include quantifying urban growth and land use dynamics, population estimation, life quality improvement, urban infrastructure characterization, monitoring land surface temperature, air quality and vegetation, and topographic mapping. Having the potential to monitor human activities at the earth surface, however, the information acquired from remote sensing data could be an additional resource in developed economies, while it might be the only alternative in the developing countries.

Despite advances in satellite imaging technology, computer-assisted image classification is still unable to produce land use and land cover maps and statistics with high enough accuracy (Lo & Choi, 2004). Image analysis techniques are evolving rapidly, but many operational and applied remote sensing analyses still require extracting discrete thematic land surface information from satellite imagery using classification-based techniques (Prenzel & Treitz, 2005). Several image classification techniques, from automated to manual digitization, can be found in the literature. However, these have spanned a broad range of land surface types and sensors. Very few studies (Carvalho, Soares, & Bio, 2006; Lee & Warner, 2006; Lo & Choi, 2004; Nangendo, Skidmore, & Oosten, 2007; Ozkan & Erbek, 2005; Prenzel & Treitz, 2005) have compared different image classification methods with different satellite sensors to determine how the organization of information inherent to the classification scheme influences classification accuracy.

Automated classification procedures of satellite imagery have been based mainly on multi-spectral classification techniques (per-pixel classifiers). These procedures assign a pixel to a class by considering its statistical similarities, in terms of reflectance, with respect to a set of classes (Gong, Marceau, & Howarth, 1992). The unsupervised classification approach provides an automated platform for image analysis, mainly based on surface reflectance and generally ignoring basic land cover characteristics (i.e., shape and size) of landforms (Chust, Ducrot, & Pretus, 2004). The supervised classification approach can preserve the basic land cover characteristics through statistical classification techniques using a number of well-distributed training pixels. However, the maximum likelihood classifier often used in supervised classification has been proven ineffective at identifying land uses at urban fringe areas due to the heterogeneity of urban land cover (Johnsson, 1994; Lo & Choi, 2004). Suburban residential areas form a complex mosaic of trees, lawns, roofs, concrete, and asphalt roadways. Such a complex urban environment develops mixed pixel problems, often causing misclassification of remote sensing images. In this case, the fuzzy supervised classification approach helps reduce mixed pixel problems in the heterogeneous earth surface by using a membership function (Wang, 1990; Zhang & Foody, 2001). However, classification techniques that combine more than one classification procedure improve remote sensing-based mapping accuracies (Lo & Choi, 2004).

Considering the complexity of the urban landscape and the importance of spectral and radiometric resolution to land use and land cover classification accuracies, we discuss the benefits of four approaches: unsupervised; supervised; fuzzy supervised and GIS post-processing. These approaches can address a wide range of mapping problems in urban frontiers and provide alternatives to improve mapping accuracies for urban planners. The objectives of this study are to derive land use land cover maps using four different mapping approaches and to compare the accuracies of the approaches in mapping urban area using Advanced Land Observation Satellite data. Tsukuba city was selected to test the mapping approaches. This city is an interesting place to study remote sensing applications as it includes both heterogeneous and homogeneous anthropogenic landscape patterns.

Methods

Study area: Tsukuba city, urban frontier of Tokyo

Geographically, Tsukuba city is situated within the geographic coordinates 35°59′42″ to 36°14′2″ North latitudes and 140°0′2″ to 140°10′39″ East longitudes, northeast of the Tokyo metropolitan fringe (Fig. 1). We considered a rectangular shape strategy covering the city and its adjacent hinterlands to remove administrative biases in mapping spatial patterns. The study site covers 55,075 ha of land. The coverage has homogeneous (i.e., paddy field, water, etc.) and heterogeneous (residential, parks, etc.) landscapes. It includes both dense and sparse types of landscape development.

The agricultural landscape of Tsukuba in the 1960s has been transformed into a modern city; in Japan the city is known as Science city. The city is well-planned and developed with a special purpose: to promote science by establishing educational institutes and national-level research institutes. Therefore, it carries a unique perspective of development by absorbing a significant number of educated populations rather than the industrial population. A high-speed train system (Tsukuba Express) was established in 2005. This transportation system makes it easy to commute and reduces the travel time to the Tokyo centre. Due to the establishment of state of the art facilities, improved life quality and reduction in travel time to Tokyo, Tsukuba is becoming the centre of attraction for the residents, even for those who are working in different parts of Tokyo. The population in the business core of Tsukuba and its vicinity is growing, with a density of 730 persons per square kilometre as of 2008; this is 25 heads higher than in 2005 (Statistics Bureau, 2008). New residential and commercial zones are being built. Rapid changes in landscape can be observed, even at a monthly or bimonthly basis.