Satellite-based multitemporal-change detection in urban environments

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High-resolution optical satellite sensors can contribute to improved coastal and land management, hazard mitigation, emergency response, and ecosystem-service design.

Urbanization is defined as the physical growth of urban areas. Improving land management depends critically on the capacity of (near)-real-time monitoring of land-use/cover change, so that solutions to a range of urban/rural-interface development issues can be managed promptly and adequately. From multitemporal to rapid-change detection, both the resolution of satellite sensors and the computational capacity of the classifiers used for image processing must be well integrated. Eventually, this may lead to improvements in coastal and land management, hazard mitigation, emergency response, and ecosystem-service design.

High-resolution satellite-based remote-sensing technology and the science associated with evaluation of land use and land cover (LULC) in urban regions use a wide range of images and algorithms for various applications.

Early remote-sensing image-classification studies employed statistical methods, such as the maximum-likelihood classifier, the $K$-nearest-neighbor algorithm, and the $K$-means clustering approach. In recent years, methods based on artificial-intelligence and machine-learning techniques have become popular. Approaches based on neural computing, fuzzy logic, evolutionary algorithms, and expert systems are widely used. Yet, existing processing techniques using LULC methods are often time-consuming, laborious, and tedious to use, resulting in the unavailability of the results within the designated time window. We developed a new image-classification approach using 2.5m-resolution SPOT-5 (SPOT: Satellite pour l’observation de la terre/satellite for earth observation) image products to investigate coastal-land-reclamation impact, urban/rural interactions, and changes of ecosystem service in Dalian (China), a fast growing city. We constructed a classifier based on the partial Lanczos extreme-learning machine (PL-ELM), a novel algorithm with fast learning speed and outstanding generalization performance.

Our case study in the Dalian Development Area (DDA) based on images collected in 2003 and 2007 (see Figure 1) fully supports the monitoring needs and aids in rapid-change detection in terms of both urban expansion and coastal-land reclamation. Since different classes of LULC outputs may have similar spectral characteristics, we extracted texture features and vegetation indices and included them in the classification process to enhance the discernability of the results. We added more features to the image pixels and introduced the ‘normalized differential vegetation index,’ as well as four commonly used texture features (angular second moment, contrast, correlation, correlation, correlation).
Therefore, we extended the feature-space dimension for all data points/pixels to eight. A validation procedure based on ground-truth data and comparisons with a number of classic classifiers proves the credibility of our proposed PL-ELM approach in terms of both classification accuracy and processing speed. We divided the LULC features into six major categories, including water bodies, forests, grasslands, bare fields, buildings, and roads. We then compared the classification accuracies for all major types, enabling us to determine the overall accuracies as well as the Kappa coefficients. Our PL-ELM classification approach outperforms five other major algorithms, including the backward-propagation neural-network, maximum-likelihood, K-nearest-neighbor and naive Bayes’ algorithms, as well as the support-vector machine.

We assessed the classification accuracy of our approach against a test data set, which consisted of 500 ground-truth data points, and fully verified the performance of the PL-ELM classifier. Figure 2 exemplifies the land-reclamation and urban-expansion processes using these statistics. From 2003 to 2007, the area covered by water decreased by 12.7206 km² as a result of coastal-land reclamation. In addition, building coverage in the region increased by 7.8086 km². This is strong evidence of rapid urban expansion. The rapid increase of the brown-colored area (which represents buildings) indicates rapid urbanization driven by population growth and migration. The exorbitant decrease of water coverage caused by coastal-land reclamation is a symbolic pattern of the DDA’s urbanization, which is driven by the prevailing land-management policy. The drastic reduction of grassland during this short time period implies a loss of ecosystem service.

In summary, we have developed a novel LULC classification approach based on an innovative machine-learning algorithm. We applied the proposed approach to two SPOT-5 image sets, acquired in 2003 and 2007, to produce six-category LULC maps with a spatial resolution of 2.5m. To improve the prediction accuracy, we extracted additional features from the original remote-sensing images, which we took into account in the classification process. To ensure urban sustainability, multitemporal variations of grasslands, water coverage, and buildings caused by urban sprawl, coastal-land reclamation, and population increase and migration, respectively, collectively reflect the main direction and connection of the urbanization process, which traces the impact of economic development. Our results will allow development of a full-scale rapid-change detection system to monitor urbanization driven by both human actions and natural disasters.
References