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A crop phenology knowledge-based approach for monthly monitoring of construction land expansion using polarimetric synthetic aperture radar imagery

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ABSTRACT

Synthetic aperture radar (SAR) remote sensing, which is independent of weather conditions, can monitor construction land expansion at short intervals for early prevention of unauthorized land use. However, seasonal crop growth creates land cover changes that are hardly distinguishable from land developments by using the traditional approach that employs two SAR images for detection. This study proposes a knowledge-based approach based on crop phenology to detect monthly construction land expansion by using consecutive polarimetric SAR imagery. The innovation of the proposed approach is the utilization of crop phenology knowledge to remove errors introduced by seasonal crop growth. In this approach, using crop phenology knowledge as a basis, a knowledge-based system is built to automatically determine when seasonal crop growth yields considerable errors. Monthly land developments are normally detected by comparing two consecutive images, but in the periods when the errors from crop growth are considerable, monthly detection results are calibrated using an additional third consecutive image, which is utilized to identify the errors based on the difference in temporal land cover change between land development and crop growth. A comparison was made between the proposed approach and the traditional approach for the monthly monitoring of construction land expansion. We found that seasonal paddy growth created many errors by using the traditional approach. The proposed approach substantially reduced these errors. Compared with the traditional approach, the proposed approach reduced errors by up to 87.33% with an average overall error rate of only 0.24%. The results indicated that the proposed approach outperforms the traditional approach in monitoring monthly construction land expansion and suppressing the disturbance from seasonal crop growth.

1. Introduction

Land use and land cover (LULC) change has been recognized as an important component of the current global change (Foley et al., 2005). One of the global trends of LULC is the expansion of construction land, which includes land for residential, commercial, and industrial use (Small et al., 2005; Seto et al., 2011). Timely monitoring of construction land expansion has become increasingly important because of the growing concern over unauthorized land development for construction, especially in developing countries such as China. The number of the unauthorized land use sites detected in the recent five years in China is as high as 385,000, involving approximately 198,000 hectares of land (Ministry of Land and Resources of the People's Republic of China, 2016). The relentless unauthorized land developments have caused many environmental and social problems, such as the rapid decline of arable land, urban sprawl, and ecological degradation, which has threatened not only the national food supply security but also sustainable urban development (Yeh and Li, 1999; Seto et al., 2000). Timely detection of construction land expansion gives advance warning to planning authorities to prevent unauthorized land use.

Optical remote sensing has been widely used for LULC mapping and monitoring (Chuvieco et al., 2005; French et al., 2008; Zhang and Weng, 2016; Chen et al., 2015), but it is usually applied to

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long-term monitoring (e.g., annual monitoring) because of the effect of weather conditions (Lunetta et al., 2004). Therefore, the use of optical remote sensing experiences difficulties in preventing unauthorized construction land expansion in the perpetually cloud-covered equatorial and tropical regions, where numerous developing countries are confronting serious problems caused by rapid urbanization. Synthetic aperture radar (SAR) remote sensing, which is nearly weather independent, has also been used for LULC investigation (Almeida et al., 2007; Soergel et al., 2009; Jin et al., 2014) and is promising for timely monitoring of construction land expansion. However, most satellite SAR systems to date have operated at a single frequency and can yield considerable confusion in LULC classification because of the limited spectral information (Li and Yeh, 2004). Polarimetric SAR (PolSAR) systems, such as RADARSAT-2 and ALOS PALSAR, have been increasingly employed to compensate for the shortcoming of single-frequency SAR systems (Whittle et al., 2012; Du et al., 2015). Using the information on the polarization state of electromagnetic waves reflected from the earth's surface, PolSAR performs significantly better than traditional single-polarization SAR in distinguishing between different LULC types (Saatchi et al., 1997; Lee et al., 2001).

Many algorithms have been proposed for PolSAR image classification and change detection. The commonly used PolSAR image classification techniques include dynamic learning neural network (Chen et al., 1996), Wishart classifier (Lee et al., 1999), and four-component method (Qi et al., 2012). Wishart likelihood-ratio test (LRT) (Conradsen et al., 2003), adaptive scale-driven approach (Bovolo and Bruzzone, 2005), and polarimetric change detector (Marino et al., 2013) are among the most widely used change detection approaches for PolSAR data. Using these classification and change detection methods as basis, a method that integrates object-oriented image analysis (OOIA), Wishart LRT, and post-classification comparison (PCC) has been developed for the monthly short-term detection of land development using RADARSAT-2 PolSAR imagery (Qi et al., 2015). OOIA allows for object-based PolSAR image classification and change detection that can decrease the effect of speckle noise and exploit various textural features for land cover classification. Wishart LRT is combined with PCC to detect different categories of land cover conversion and reduce the limitation posed by classification accuracies to detection accuracy. Compared with the traditional pixel-based PCC, this integrated method attains a significantly higher accuracy of detecting land development for construction.

The previous study has also indicated that traditional approaches that use two consecutive PolSAR images for detecting construction land expansion face a significant challenge caused by seasonal crop growth (Qi et al., 2015). Land development for construction typically causes changes from vegetation to barren land and from other land cover types to built-up areas, and therefore can be spotted by detecting these two types of change. The problem is that seasonal crop growth can yield false alarms by creating the same types of change. For example, changes from vegetation to barren land can be due to land clearing and leveling for either construction or crop plantation. In addition, crops in certain stages of their growth are easily confused with buildings in PolSAR images. Thus, changes caused by the growth of these crops can be erroneously interpreted as conversions from barren land to built-up areas (Qi et al., 2015). The effect of seasonal crop growth can be effortlessly avoided in long-term change detection using the images acquired at the same time in different years. In the monthly monitoring of construction land expansion, seasonal crop growth presents a significant problem that is difficult to circumvent.

A knowledge-based approach based on crop phenology is proposed in this study to overcome the problem caused by seasonal crop growth. The central premise of this approach is that false alarms produced by crop growth will recover to vegetation within a short time because of the continuous crop growth. This approach requires a prior knowledge of crops that can affect the detection of construction land expansion; this information can be easily obtained through the typical characteristics of such crops ascertained by this study. Using the knowledge of the phenology of these crops as a basis, a knowledge-based system is built to identify when seasonal crop growth produces considerable errors. Two consecutive PolSAR images are normally employed to detect monthly construction land expansion. In the periods when crop growth creates considerable errors, an additional third consecutive image is utilized to calibrate detection results by removing these errors. The detected land developments that turn out to be vegetation in the third image are determined as false alarms introduced by crop growth. The knowledge-based approach is compared with

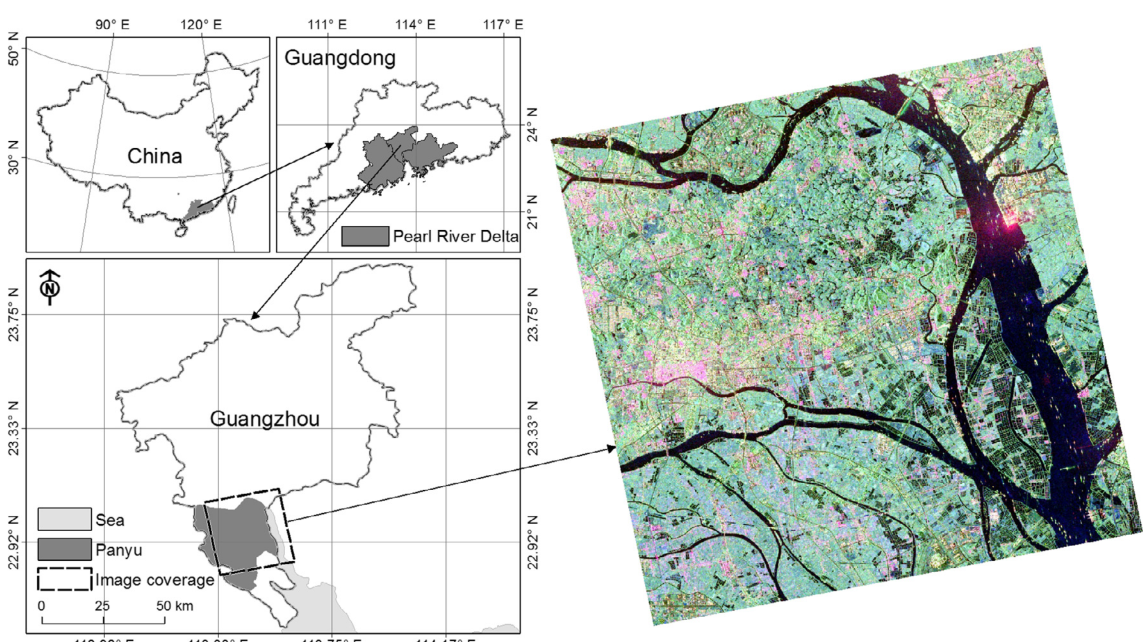

Fig. 1. Study area and a RADARSAT-2 PolSAR image (Pauli RGB composition).