Foreword to the Special Issue on Recent Advances in Processing of High-Spatial-Resolution Remote Sensing Data

SINCE the launch of the first high-spatial-resolution (HSR) remote sensing satellite (IKONOS, in September 1999), we have been entering a new era of high-resolution earth observation (EO). A variety of high-resolution remote sensing platforms continue to emerge. For instance, the new generation of the WorldView-3/4 satellites can provide high-resolution and super-spectral images, and their extraordinary ability allows them to simultaneously and accurately depict the spectral-spatial properties of the land surface. The HSR imaging radar (SAR) satellites, e.g., Cosmo-SkyMed, TerraSAR-X, and Gaofen-3, are capable of gathering high-resolution information independent of weather conditions. In particular, ZY-3, China's first civilian high-resolution satellite, carries high-resolution multiview cameras, including forward, nadir, and backward modes [items 1) and 2) in the Appendix]. This notable advantage enables us to obtain three-dimensional (3-D) EO data, and facilitates a number of new applications. Smart satellites (e.g., planet labs) have to be mentioned due to their high revisit frequency, i.e., achieving daily coverage of the earth. In addition, unmanned aerial vehicles (UAVs) have also received increasing attention, thanks to their timely, flexible, and efficient data acquisition capacity.

In this context, advanced processing methods for HSR imagery are of great interest, e.g., HSR multisensor fusion [item 3) in the Appendix], deep change analysis [item 4) in the Appendix], deep learning [items 5)–7) in the Appendix], and in the meantime, a series of new application scenarios are continuing to appear, such as building height learning and estimation [items 8) and 9) in the Appendix], social functional mapping [items 10) and 11) in the Appendix], local climate zones classification [item 12) in the Appendix], slum mapping [item 13) in the Appendix], large-scale object detection and tracking [items 14) and 15) in the Appendix], monitoring ecosystem service [item 16) in the Appendix], and 3-D urban heat island interpretation [item 17) in the Appendix]. Therefore, it is timely for this special issue to exhibit and discuss the recent advances in HSR remote sensing.

This issue intends to introduce recent advances in the HSR data processing. It contains 15 papers, mainly concerning the preprocessing (one paper), deep learning (four papers), superresolution (two papers), object recognition (three papers), object-based image analysis (OBIA) (two papers), and applications (three papers).

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I. PREPROCESSING

Gholinejad *et al*. [item 18) in the Appendix] focused on the geometrical correction of HSR imagery. The traditional rational function model is usually subject to the overparameterization problem owing to their highly correlated coefficients. To this end, recently, a series of algorithms have been proposed to cope with this issue, e.g., the particle swarm optimization (PSO), aiming to find the optimal coefficients. However, the performance of the algorithm can be influenced by the initialization and the limited number of ground control points. Therefore, Wurm *et al.* [item 13) in the Appendix] proposed a modified PSO method by considering the k-fold cross validation. Their experimental results validated the robustness of the method and its superiority to the state-of-the-art ones.

II. DEEP LEARNING

In this issue, it is not surprising that the topic of deep learning attracts the most attention. Du *et al*. [item 19) in the Appendix] attempted to develop and improve the pretrained convolutional neural networks (CNN) for feature representations. Specifically, two subspace learning methods were used to extract the multilayer features from a single pretrained CNN and then extend it to the multi-CNN models for classifying two public and challenging HSR datasets. Their results demonstrated the effectiveness of the transferred pretrained networks and the proposed fusion strategy for scene classification, compared to the conventional methods.

Peng *et al*. [item 20) in the Appendix] proposed a series of strategies to modify and refine the convolutional networks, considering the limitations of the existing CNN models, e.g., gradient explosion and overfitting. First, they formed a densely based fully convolutional networks (DFCNs) by combining dense connection and fully convolutional networks. The DFCN was then strengthened via a set of multiscale filters to enrich the extracted features, which are more robust than the original convolutional information. In addition, the authors also tested the effectiveness of the proposed networks by integrating the digital surface models information into the model. Their experimental results were assessed on the public dataset for semantic segmentation, with comparable accuracy achieved compared to the state-of-the-art algorithms.

Object-based building extraction is an active research topic, but it is usually subject to the issues of oversegmentation and scale parameter. Meanwhile, it is difficult to deal with the transferability of the object-based image processing methods, considering the complexity of the segmentation results. In this context, Majd *et al*. [item 21) in the Appendix] proposed an object-based deep CNN model and attempted to address the aforementioned problems by selecting the optimal CNN from a series of configurations of CNNs. The effectiveness of the proposed method was shown in the Vaihingen dataset, and its transferability was validated in a different sensor (WorldView-2).

Although CNNs have obtained much success for remote sensing image classification, the current models are seemingly becoming increasingly complex by combining multiple networks or feature sources. In this context, Zhang *et al*. [item 22) in the Appendix] designed a lightweight CNN based on MobileNet V2, and the dilated convolution and channel attention were adopted for feature extraction. In addition, the multiscale features were represented using a multidilation pooling module. Six datasets were used to validate the proposed networks with comparable accuracy obtained to the existing mainstream methods.

III. Superresolution

Two papers are concerning superresolution. One lays particular attention to a specific sensor (GF4 satellite), but the other emphasizes the reconstruction method. Wang *et al*. [item 23) in the Appendix] addressed the superresolution of GF-4, which is the first civilian geostationary orbit high-resolution satellite of China, using the multi-image approach. The basic idea of the proposed method is to fuse the original spectral images with the reconstructed high-resolution texture information achieved by the projection onto convex sets algorithm. The proposed method can obtain higher reconstruction quality in terms of a set of quantitative metrics. Shao *et al*. [item 24) in the Appendix] addressed the superresolution, and they proposed a coupled sparse autoencoder method to learn the relation between the sparse coefficients derived from the high-resolution and low-resolution images.

IV. Object Recognition

The papers for object recognition refer to buildings, shadow, and tailings ponds. It is interesting to see that the three research papers adhere to the traditional routes, i.e., feature representation, but do not involve deep learning.

Hao *et al*. [item 25) in the Appendix] proposed an active building extraction method, on the basis of visual perception theory. Specifically, they presented that the main direction and color information can reflect the characteristics of the building outline, and subsequently, the textural and geometrical features can be used to detect buildings accurately.

Fang *et al*. [item 26) in the Appendix] presented a shadow index, based on the normalized difference between the saturation and near infrared channel. The basic idea is that shadow regions usually show small response in the near-infrared band, but other objects (e.g., vegetation, buildings, and roads) do not. But the authors admitted that the proposed shadow index should be further tested in other sensors and more complicated image scenes.

Liu *et al*. [item 27) in the Appendix] concerned the detection of the tailings ponds, owing to their threat to neighboring inhabitants and ecological environments. Conventionally, the monitoring of the tailings ponds was difficult, and relied on manual visual interpretation, considering their heterogeneous and complicated spatial composition. In this research, the authors attempted to identify the targets by investigating the spatial combinations of their main structures, including starter dams, embankments, deposited beach, and water body. After several steps of postprocessing, satisfactory results were obtained, achieving 88%–97% overall accuracy, which was significantly higher than the random forest classifier.

V. Object-Based Image Analysis

OBIA is a classic problem for HSR data processing. It refers to a series of research points, e.g., segmentation, feature extraction, rule-based classification, machine learning, and object recognition. In this special issue, we have two papers for OBIA, with one for the segmentation quality assessment and the other for the segmentation algorithm. Notice that in Section II, there is one study trying to combine OBIA and deep learning.

Wu *et al*. [item 28) in the Appendix] proposed a hierarchical segmentation evaluation method for evaluating the segmentation quality. This is an important issue for OBIA, and the authors claimed that their method can be further used to select and optimize the scale parameter. Zheng *et al*. [item 29) in the Appendix] developed a hybrid Markov random field model by taking the multigranularity information into account, for segmentation of HSR imagery. This idea is based on the fact that the current segmentation methods often consider single-layer granularity, e.g., pixel or object. Specifically, the different granularities information is represented and integrated in a multilayer probability graph.

VI. Applications

Fan *et al*. [item 30) in the Appendix] employed GF-3, the first full polarimetric synthetic aperture radar satellite of China, for detecting the marine floating raft aquaculture. In order to strengthen the detection accuracy, an unsupervised collective multikernel fuzzy C-means (CMK-FCM) algorithm was proposed to deal with the SAR and its textural features. Their experiments revealed the satisfactory performances of GF-3 and the proposed multifeature fusion achieved by the proposed CMK-FCM algorithm.

As a typical application scenario for disaster response, high-resolution imagery has potential for monitoring and evaluating the damaged buildings in an earthquake. Liu and Li [item 31) in the Appendix] proposed a new object-based homogeneous index as well as an object histogram approach in order to extract collapsed buildings. The proposed method is based on the consideration that the intact objects show substantially distinct characteristics compared the collapsed buildings. The bitemporal QuickBird images, acquired for the earthquake of Dam, Iran, in 2003, were used to assess the performance of the proposed strategy. In their experiments, the efficiency has been validated.

Zhang *et al*. [item 32) in the Appendix] investigated the extraction and segmentation of glacial lakes on the basis of SAR data, considering its all-weather observation ability, i.e., regardless of weather and solar conditions. The current difficulties for SAR-based lake detection lie in the noise and low contrast. To cope with these issues, the authors presented a phase-congruency-based detector, which is able to represent the geometrical and textural features of the glacial lakes. Their experiments were conducted on the Sentinel-1A/1B images of the Himalayas, with accurate segmentation achieved, i.e., the relative errors were smaller than four pixels for all the lakes.

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APPENDIX
RELATED WORK

1) X. Huang, D. Wen, J. Li, and R. Qin, "Multi-level monitoring of subtle urban changes for the megacities of China using high-resolution multi-view satellite imagery," *Remote Sens. Environ.*, vol. 196, no. 1, pp. 56–75, Jul. 2017.
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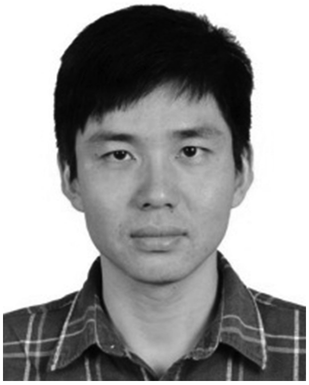

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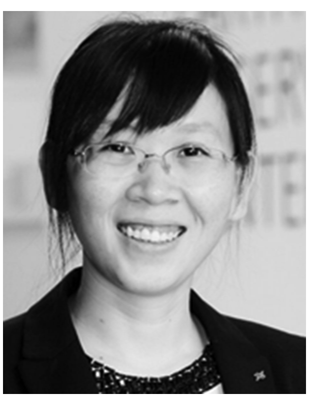

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