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Computationally-efficient sequential feature extraction for single hyperspectral remote-sensing image classification

Andong Ma [a, *], Anthony M. Filippi [a]

[a] *Department of Geography, College of Geosciences, Texas A&M University, College Station, TX, 77843, USA, adma@tamu.edu, Anthony M. Filippi, filippi@tamu.edu*

* Corresponding author

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Abstract:

Remote sensing (RS) is an important technology for Earth observation, where detailed physical and chemical properties of the Earth can be remotely characterized. Hyperspectral images (HSIs), which are collected from a sensor where the spectral width of each band is narrow compared with other (broadband) optical sensors, yield continuous spectra that can be used to distinguish those ground objects with similar spectral features. In order to process and analyse HSIs, classification, where each pixel in a HSI is assigned to a predefined label based on a specific machine-learning model, for example, is a widely-used technology. Over the past decade, deep learning, a subset of machine-learning methods, has been increasingly employed due to its accurate performance in various research subfields, including computer vision, medical image analysis, speech recognition, and nature-language processing. For the RS and HSI communities, deep learning has been successfully utilized since 2014. Since then, varied deep learning-based approaches have been proposed, including deep neural networks (DNNs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs). Among those deep-learning models, RNNs have been increasingly been applied to the problem of RS image processing, especially multi-temporal image analysis, due to their great capacity for handling sequential data. However, for the particular case of RNN-based classification of single RS images, further research is required. The key question in this scenario is how to extract the sequential feature for each pixel. To address this issue, various researchers have explored and proposed different solutions which can be summarized into two main categories: Given a target pixel, the first strategy is to utilize the spectral feature as its sequential feature. The second strategy is to extract "similar" pixels from the image and exploit those "similar" pixels to construct a sequential feature of a target pixel. Based on our previous work [1], we proposed a similarity-measurement-based RNN HSI classification model where the sequential feature of a target pixel is encoded by first utilizing several "similar" pixels extracted from the whole image. Although the classification performance of this proposed framework is much better than other standard algorithms, its computational time cost is still a critical issue. Therefore, how to develop a more computationally-efficient sequential feature-extraction method within the RNN-based classification domain still needs more investigation for the single-image classification problem.

Based on our previous work [1], we propose an improved sequential feature-extraction framework for single HSI-based classification using RNN. The main contribution of the present research effort is to modify the searching range of the similarity measurement such that it is shrunk from the whole-image pixel set to one or two similar segments created by an object-based segmentation algorithm. The effect is that similar pixels of a target pixel will not be extracted from all pixels of the image, but rather from similar segments generated from a segmentation map derived from the fractal net evolution approach (FNEA) model, which is a well-known multiresolution segmentation algorithm. Specifically, for our proposed method, we design a two-phase similarity measurement: 1) segment-similarity is first calculated in order to select similar segments; and 2) pixel-similarity is then obtained, utilizing those pixels collected from selected "similar" segments. After pixel-similarity calculation, similar pixels can be extracted to construct sequential features in the same manner as what we proposed in our previous work [1]. During the calculation of segment-based similarity, both spectral and geometry features of those segments are considered in order to better characterize properties of the segments. For the selection of similar segments, we develop three different strategies, including: 1) a local segment-based approach where only the segment that contains the current target pixel is taken into consideration; 2) a non-local segment-based approach, where the second most similar segment is selected instead of the current segment; and 3) a mixed segment-based approach, where the two aforementioned segments are utilized simultaneously. Moreover, pixel-matching (PM) and block-match (BM) proposed in our previous work [1] are employed as well when measuring similarity between two individual pixels.

To assess classification performance, three benchmark HSIs are utilized including the Pavia University HSI, the Salinas HSI, and the Indian Pines HSI. Meanwhile, the models proposed in [1] are assessed as well, as they are considered to be a baseline for the evolution of computational time costs. In addition, other benchmark algorithms, including support vector machine (SVM), the 1-dimensional convolutional neural network (1DCNN), and the 1-dimensional RNN (1DRNN), are utilized as well. The results demonstrate that our proposed models obtain better classification accuracies

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compared with other evaluated algorithms. For the Pavia University and Salinas HSIs, using the mixed segment-based approach yields the highest accuracy, with 96.89% and 96.64% overall accuracy (OA), respectively. Regarding the characterization of the classification maps, apparent improvements in classification performance can be visually observed. For the Indian Pines HSI, the best results are obtained from the local segment-based model instead of the mixed segment-based approach, with 94.04% OA. We also evaluate the computational costs for both the proposed models and the ones in our previous work [1]. We find that such time costs are reduced significantly, by more than one hundred times. For example, for the Pavia University HSI, the time cost of our previous model is 4155.98 seconds. However, such a cost for the proposed model utilizing the local segment-based approach is 40.63 seconds. Such results demonstrate that those proposed approaches are capable of achieving satisfactory classification accuracy, while still obtaining markedly lower computational time cost.

Reference:

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