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Locality-constraint discriminant feature learning for high-resolution SAR image classification

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ABSTRACT

It remains one of the most challenging tasks to distinguish different terrain materials from a single SAR image. With the increase of ground resolution, it allows us to model the SAR image directly by exploiting spatial structures and texture information that are extracted by several machine learning approaches. In this paper, a novel feature learning approach is proposed to capture discriminant features of high-resolution SAR images. In the first stage, a weighted discriminant filter bank is learned from some labeled SAR image patches to generate low-level features. Then, the locality constraint is introduced to produce the high-level features in both the encoding and the spatial pooling procedure. In this work, the superpixels are employed as the basic operational units instead of the pixels for terrain classification. With some learned domain patterns which are learned from all of the high-level features of each pixel, the superpixel is characterized by a hyper-feature. In the last stage, a linear-kernel support vector machine is utilized to classify all of these hyper-features which are generated for each superpixel. The experimental results show a better classification performance of the proposed approach than several available state-of-the-art approaches.

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1. Introduction

In recent years, a large number of high-quality SAR images have been emerged for various civil and military applications [1–3] since many high-resolution SAR sensors have been launched, such as TerraSAR-X, COSMO-SkyMed, E-SAR, Sentinel-1, F-SAR and so on. Distinguishing different terrain materials in a single SAR image is one of the most active research topics for SAR image understanding and interpretations, such as land cover classification [4,5], urban detection [6] and environment risk evaluation [7,8]. However, it is still a challenge to extract discriminant features to characterize different SAR materials. Most of the previous SAR image classification works are focused on labeling each pixel with some pre-defined terrain categories by exploiting the spectral, textual and contextual information [9,10]. With the increase of resolution, how to organize these local structures in an effective way is becoming the key technique to produce the discriminant descriptors to characterize complex terrain scene of the high-resolution SAR images.

Recently, several high-level feature descriptors which have been widely used in the literature of computer vision are developed to characterize the content of SAR images. The bag-of-visual-words (BoVW) model [11,12] is one of the most popular approaches which are utilized to combine all of the local features into a global descriptor to characterize the specified terrain materials. However, it is incapable to capture the shape and location information as the inter-correlations among spatial layout of various local structures are disregard. Although the studies of [13,14] indicate that sparse coding is another effective method to describe different SAR terrain materials compared with the BoVW approach, the computational cost of sparse optimization is high as a result of non-convexity in coding procedure. Recently, many studies [15–17] show that the locality-constraint is essential in the feature learning and encoding procedure. In this work, the locality-constraint is also exploited to produce the high-level features of the high-resolution SAR (HRSAR) images.

In addition to these high-level features, it is also an essential part to produce the discriminative low-level features for SAR image classification. The texture descriptors [18,9] which are some statistics of gray-level co-occurrence matrix (GLCM) are the most popular low-level features to describe SAR images. Besides, the filter features that are captured by the Gabor filter bank [19,20] and wavelet transform [21,22] are also widely utilized to capture the texture patterns with some pre-defined scales and orientations. However, it

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is difficult to determine a suitable number of scales and orientations of the filter bank to extract enough information to characterize the content of HRSAR images. In recent years, the contextual descriptor [23] and adaptive neighboring based local primitive [24] have also been employed to exploit the complex structure from HRSAR images. As it is easy to implement and has low computational complexity, the filtering approach is used in this paper to extract the low-level features of HRSAR images. A bank of weighted discriminative filters (WDFs) is learned from the labeled SAR images to produce the low-level features in this work. It consists of two parts which are a bank of category-adaptive filters and a weighted neighbor sampling mask. All of these two parts are learned from the labeled SAR images to capture enough discriminative information.

In this work, a locality-constraint discriminant feature learning (LCDFL, shown in Fig. 1) approach is proposed to learn high-level features to characterize HRSAR images. To perform SAR image classification, the superpixels are employed as the basic operational units instead of pixels. Specially, the proposed LCDFL consists of three major steps, which are filtering, feature coding and spatial pooling. In the first step, the discriminant low-level features are generated by filtering with a weighted discriminant filter bank which is learned from the labeled SAR samples in the training set. Then, all these low-level features are encoded to generate the high-level features by utilizing a codebook that is learned by introducing the locality-constraint prior. And finally, a spatial pooling procedure is introduced to obtain the features of each superpixel with some domain patterns (DPs). The major contributions of this work are listed in the following.

1. A bank of weighted discriminative filters which are learned from the labeled SAR image samples is utilized to capture the low-level features of SAR image pixels.
2. The locality-constraint prior utilized in this work is implemented in two aspects. Firstly, each low-level feature is encoded to formulate the high-level feature with a codebook that are learned with consideration of the locality-constraint. Then, each superpixel of the SAR image is characterized by pooling all of the high-level features appeared in a local spatial neighborhood after partitioning the image into several superpixels.

The classification performance of the proposed approach shows a better results than several state-of-the-art approaches in the experiment section.

The remainder of this paper is organized as follows. In Section 2, we briefly review the works of feature descriptors which exploit structural and spatial information for HRSAR terrain classification in recent years. The propose approach is evaluated and compared with several state-of-the-art approaches in Section 3. In Section 4, we introduce the general framework of the proposed LCDFL approach. The proposed approach is evaluated and compared with several state-of-the-art approaches in Section 5. And finally, we make some conclusions and future works in the last section.

2. Related works

Recently, a study on the performance of information extraction techniques with respect to different imaging parameters and the selected primitive features has been proposed in [25]. Many primitive features were checked on TerraSAR-X images with different imaging modes, such as Gabor filter bank, GLCM, quadrature mirror filters and non-linear short-time Fourier transform. It shows that the classification accuracy varies with different choices of imaging mode and the selected primitive features. These primitive features are often combined together to formulate a complex feature to capture richer information in many of the practical

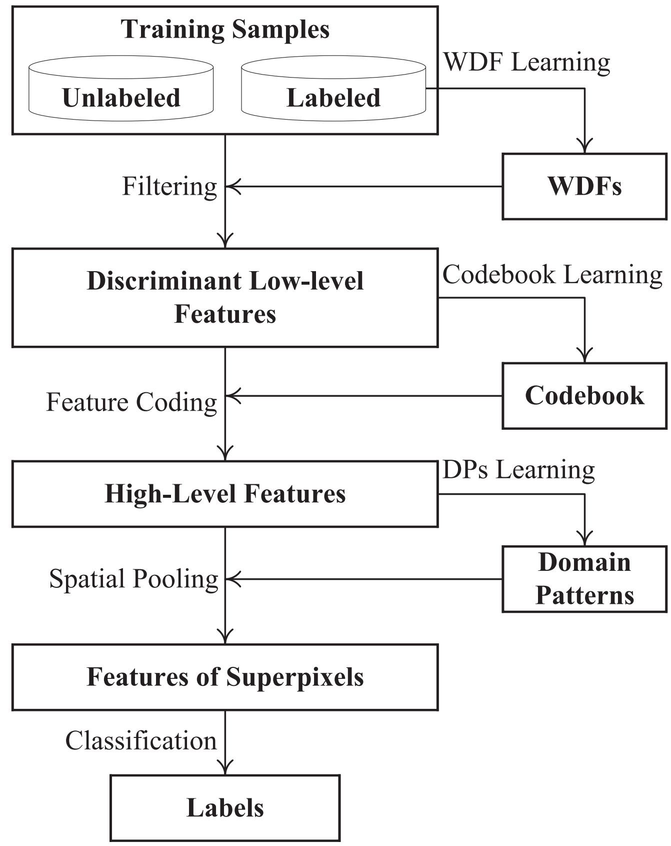

Fig. 1. Pipeline of the proposed locality-constraint discriminative feature learning (LCDFL) approach.

applications, such as the Gabor filter and GLCM [9,26]. However, it is difficult and confusing to determine a feasible number of gray-level intervals of GLCM to capture enough statistical information with low computational cost. For filters, the number of scales and orientation of filters should be determined in advance. And also, the spatial information which is utilized by these primitive features is exploited in a limited way, which is essential to characterize the complex structure of HRSAR images.

In order to capture enough spatial information, the contextual relations of the pixels or superpixels should be considered in feature extraction procedure of HRSAR images. The Markov random field (MRF) model [5,27,28] is one of the most popular approaches to generate smooth classification and segmentation results by taking the contextual relations into consideration. By incorporating the Gamma distribution, Deng et al. [29] proposed a MRF model to seamlessly combine spatial relations of various features to discriminate sea ice from water. Although the Gamma distribution is appropriate to describe sea ice, it is still a difficult task to determine some available distribution of the intensity value from the other terrain materials, such as farmland, urban areas, forest and so on. Based on wavelet transform, a region-based hierarchical MRF [26] was proposed to extract features of SAR image for classification and segmentation by exploiting both the inter-lay and intra-layer relations. However, some fine details were failed to detect as the smoothness assumption was introduced over sub-regions. Voision et al. [30] developed a hierarchical MRF model for HRSAR image to extract urban areas by combing the amplitude data and texture information. The texture information is produced by a quad-tree model and an innovative statistical model. Although the classification results present high accuracy on all the tested urban, water and land separation, there are still some smoothing effects at the spatial borders between different terrain

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