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Information integration for ground-based cloud classification using joint consistent sparse coding in heterogeneous sensor network

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ABSTRACT

Although sparsity-based algorithm has emerged as an extremely powerful tool for information integration, it neglects the relationship of heterogeneous features and coding coefficients from the same class in the training stage, which may cause declining of the classification performance. In this paper, we focus on information integration for ground-based cloud classification in heterogeneous sensor network (HSN), and propose a novel coding strategy named joint consistent sparse coding (JCSC) to overcome the drawbacks of traditional sparse coding. In order to integrate information effectively, we add a joint sparse regularization to learn the relationship of heterogeneous features. Moreover, we utilize the consistent constraint on coding coefficients. In this way, coding coefficients from the same class can be forced to their mean vector, and therefore they are more compact and discriminative. The experimental results demonstrate that our method achieves better performance than the state-of-the-art methods.

1. Introduction

Clouds, which are one of the most important meteorological phenomena related to the hydrological cycle, play an essential role in the earth radiation balance and climate change. Ground-based cloud classification, as an important cloud observation technique, has received more and more attention from the research community. It is because successful cloud classification can improve the precision of weather prediction and help us to understand atmospheric conditions. Moreover, cloud classification could assist us arranging flight and aviation plan. Clouds are currently studied using both satellites and ground-based weather stations. Some work focuses on classification of clouds based on satellite images [1,2]. Most of these methods utilize texture metrics to represent the cloud images and neural networks to distinguish among different cloud types. However, the information extracted from large-scale satellite images fails to capture the details of cloud because these images generally possess low resolution. On the contrary, ground-based cloud observations are able to obtain richer, more accurate retrievals of cloud information. Hence, ground-based cloud classification has received much attention. At present, ground-based clouds are traditionally classified by human observers who have received professional training [3]. Despite their unquestionable usefulness, different observers will obtain discrepant classification results and it is time-consuming. Therefore, automatic ground-based cloud classification technique is urgently needed in this field.

The automatic cloud classification is a challenging task due to the extreme appearance variations under different atmospheric conditions, which makes this issue under development. In recent years, a lot of ground-based imaging

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devices have been developed for capturing cloud images, which provides hardware supporting for automatic cloud image classification. The sky images can be obtained by these devices, such as the whole sky imager (WSI) [4,5], total sky imager (TSI) [6], infrared cloud imager (ICI) [7,8], all-sky imager (ASI) [9,10], the whole-sky infrared cloud-measuring system (WSIRCMS) [11], and so on. Besides, the rapid development in the field of signal processing and pattern recognition provides an effective solution for cloud classification. Existing cloud classification techniques are generally based on the characteristics of structure and texture in cloud images. The algorithms based on structure features include cloud fraction and edge sharpness [12], and Fourier transformation [13]. While the algorithms based on texture features include Law's measures [14], co-occurrence and auto-correlation matrices [15], and local binary patterns and its extensions [16,17]. In addition, several algorithms [3,5] are proposed to employ these two characteristics as the final representation.

Although these above works have been done on this topic, they only utilize one kind of sensor, i.e., image sensor, to capture the cloud information, and fail to fully explore useful information for clouds. The clouds, as one kind of natural resources, usually possess very large intra-class variations due to the large variation on illumination, climate and deformation. The cloud type is determined by many factors, for example, humidity, temperature and pressure. Hence, the image sensors are difficult to obtain the complete cloud information. Inspired by the recent advances in heterogeneous sensor network (HSN), we consider to classify the ground-based cloud in HSN. The HSN is composed of a number of heterogeneous sensor nodes, for example, image sensors, thermal sensors, and moisture sensors, which forms a sensor field and a sink [18,19]. These large numbers of heterogeneous nodes have the abilities to obtain multimodal information of clouds. The visual, thermal, and moisture information could collect more complete information for ground-based cloud information with the help of HSN, so the limitation of each kind of information could be compensated.

Recent studies show that integrating multiple types of information can improve recognition performance [20,21]. Hence, how to integrate these heterogeneous informations in HSN is a key to ground-based cloud recognition. Information integration could be roughly grouped into three kinds, namely feature-level integration, kernel-level integration and score-level integration, as shown in Fig. 1. In the feature-level integration, some researchers propose direct concatenation of weighted heterogeneous features as the final feature for subsequent classification [22,23]. Nevertheless, such methods may result in dimensionality curse due to the concatenated high dimensional feature. Additionally, by simply combining all heterogeneous features may not be necessary to improve the performance of classification because not all features are reliable. Kernel-level integration utilized a linear combination of kernel matrices where each kernel corresponds to one kind of feature. It is equivalent to directly concatenating each kind of feature, and then import to the support vector machine (SVM) with linear kernel. The kernel average is more effective than the other kernel-level integration algorithms

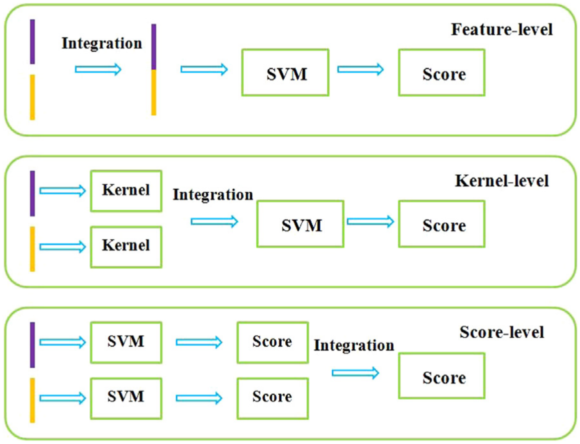

Fig. 1. Different pipelines for information integration.

when only limited kernels are considered [24]. In score-level integration methods, a classifier is trained by each kind of feature, and then the confidence score of each classifier is integrated [25].

Feature-level integration is widely applied in classification task. It is because data processing inequality (DPI) [26] indicates that the feature level contains more information than that in the score level. Therefore, feature-level integration should make use of the more discriminative features for cloud classification. Since the sparse coding model has been proposed as a very effective method for texture and image classification [27–29], it is recently employed to integrate the heterogeneous features in the feature level. The multi-task joint sparse representation (MTJSR) [30,31] is representative among the sparsity-based integration methods. MTJSR utilized a sparsity norm to discover the class-level joint sparsity patterns among heterogeneous features. Thus, the information in the heterogeneous features can be mined by this sparsity constraint. In addition, high dimensional features are represented by low dimensional reconstruction coefficients, which could alleviate the dimensionality curse. However, directly applying the MTJSR for ground-based cloud classification in HSN may not achieve promising performance, because MTJSR is built on the assumption that all representation tasks are closely related and share the same sparsity pattern. This assumption is rigid for ground-based cloud classification in HSN due to the uncorrelated data captured from image sensors, thermal sensors, and moisture sensors in HSN. Moreover, in the training stage, the dictionary and coding coefficients of heterogeneous features are iteratively learned class by class. The training stage, however, neglects the relationship of coding coefficients from the same cloud class. We expect the coding coefficients from the same class to possess the characteristic of compactness. Namely, the coding coefficients from the same class should be similar.

In this paper, to overcome the above drawbacks, we propose a novel algorithm named joint consistent sparse coding (JCSC) to integrate information for ground-based cloud classification in HSN. We utilize joint sparse regularization to mine the common patterns from heterogeneous