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Scene-free multi-class weather classification on single images

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A R T I C L E I N F O

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A B S T R A C T

Multi-class weather classification is a fundamental and significant technique which has many potential applications, such as video surveillance and intelligent transportation. However, it is a challenging task due to the diversity of weather and lack of discriminate feature. Most existing weather classification methods only consider two-class weather conditions such as sunny-rainy or sunny-cloudy weather. Moreover, they predominantly focus on a fixed scene such as popular tourism and traffic scenario. In this paper, we propose a novel method for scene-free multi-class weather classification from single images based on multiple category-specific dictionary learning and multiple kernel learning. To improve the discrimination of image representation and enhance the performance of multiple weather classification, our approach extracts multiple weather features and learns dictionaries based on these features. To select a good subset of features, we utilize multiple kernel learning algorithm to learn an optimal linear combination of feature kernels. In addition, to evaluate the proposed approach, we collect an outdoor image set that contains 20 K images, called MWI (Multi-class Weather Image) set. Experimental results show the effectiveness of the proposed method.

1. Introduction

Most of the existing methods in the field of computer vision are based on the assumption that the weather in outdoor images or videos is clear. However, different weather conditions such as rain, snow or haze will decrease the quality of images or videos, as shown in Fig. 1. Such effects may significantly degrade the performances of outdoor vision systems which relies on image/video feature extraction or visual attention modeling. Hence, the applications of weather classification are numerous, such as the detection and observation of weather conditions, image/video analysis, the reliability improvement of video surveillance systems. In this paper, we target at the problem of classifying multiple weather, such as sunny, rainy, snowy, and haze from single images.

Despite its remarkable value, multi-class weather classification has not been thoroughly studied. Some previous researches [1–3] focused on weather recognition from vehicle camera images for driver assistance. Most of these methods are only able to recognize rainy weather. Furthermore, the applications are limited due to the relatively fixed target scenes. Recently, the authors of [4,5] focused on two-class weather recognition, include sunny and cloudy. The authors of [4] estimated the weather conditions of popular tourism from images of the same scene. The authors of [5] proposed a collaborative learning framework via analyzing multiple weather cues for two-class weather recognition from single images. The authors of [6] proposed a method to label images of the same scene with three weather conditions including sunny, cloudy, and overcast. The authors of [7] proposed an approach for multi-class weather classification, which could be used for the traffic scene only. However, approaches for the fixed scene weather classification are not able to be applied in the practiced systems due to the following two reasons. First, it needs to learn different classifiers for different scenes. Second, it is hard to collect the training image set in any scene. The darkness in the night is another factor that results in the decrease of image quality. The authors of [8] proposed a Color Estimation Model for night removal from a single input image. They use a guided statistical Dark-to-Day prior to direct optimal performance.

Different from the above works, we propose a new framework for classifying multi-class weather from single images in any scene, which is based on dictionary learning and multiple kernel learning (MKL). Implementation of the kernel idea, however, entails substantial challenges. First, it is difficult to find suitable features to discriminate different weather conditions. Second, the features might be heterogeneous and the feature vectors are high-dimensional. Aiming at solving the above challenges, we first extract multiple features to represent different weather conditions. For example, the sky and shadow features can indicate

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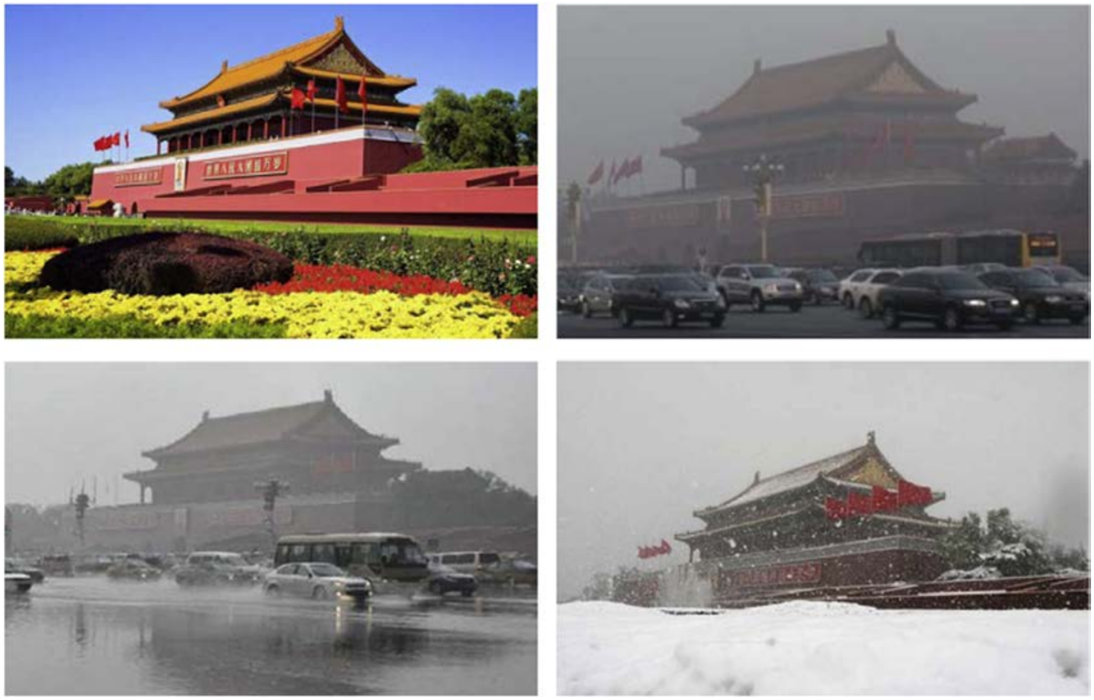

Fig. 1. Tiananmen Square in different weather conditions.

sunny weather. The dark channel feature can indicate the haze weather. The HOG (Histogram of Oriented Gradients) based template matching feature can indicate rainy weather. The snowflake noise feature can indicate snowy feature. Some global features like contrast and saturation are used to distinguish multi-class weather. To improve the discrimination of image representation and enhance the performance of multiple weather classification, our approach extracts multiple weather features and learns multiple dictionaries based on these features. Then, we use multiple kernel learning algorithm to learn an optimal linear combination of feature kernels for selecting a good subset of features.

The contributions of this paper are as follows:

- We propose a scene-free multi-class weather classification framework by fusing multiple image features and learning multiple dictionaries. To our knowledge, this work is one of the first attempts towards single image multi-class weather classification.
- We propose two methods for detecting rain streak and snowflake from single images respectively. First, we propose a Histogram of Orientation Gradients (HOG) based template matching method to detect the rain streaks. Moreover, we regard snowflake as a kind of noise and define several rules to detect and describe snowflakes.
- We collect an outdoor image set contains 20 K images called MWI (Multi-class Weather Image) set, which provides an extensive testbed for the evaluation of existing methods and development of new approaches.

2. Related work

In this section, we give a brief review on dictionary learning and multiple kernel learning.

2.1. Dictionary learning

Dictionary learning is an effective feature learning technique. It has been successfully applied on a variety of problems in computer vision [9] and image analysis [10]. For image classification tasks, the learned dictionary can be used to represent images, which facilitates classification. The authors of [11] proposed a supervised learning method to learn a dictionary in the source image space and a corresponding transformation matrix. The learned global transformation matrix was used to map sparse features of source image patches to intensity values of the target patches. The authors of [12] proposed a sparse coding technique in a high dimensional feature space by using some implicit feature mapping. They applied it to image classification, face recognition, and kernel matrix approximation. However, these works focus on basic-level object classification that might fail in weather classification task, because the difference between different weather conditions is subtle and minute.

Some scholars put a lot of effort in the research on fine-grained classification via dictionary learning. The authors of [13] learned a hybrid dictionary with commonalty and particularity that integrated an incoherence penalty term into the objective function for obtaining the class-specific sub-dictionary. The combination of the particularity and the commonality can faithfully represent the samples, and the particularities are more discriminative and more compact for classification. The authors of [14] learned both category-specific dictionaries and a shared dictionary to separate the different and common components of each image for fine-grained categorization. They proposed to impose cross-dictionary incoherent constraint and self-dictionary incoherent terms in the objective function for learning a discriminative dictionary.

2.2. Multiple kernel learning

In recent years, many good features have been designed to characterize various aspects of an object. However, simple classifiers cannot handle the high-dimensional feature space well. Thus, a proper feature selection and fusion is required for discarding irrelevant features and adapting the model to the specific problem.

Multiple kernel learning [15] is viewed as an effective way to fuse features and design an optimal kernel [16,17]. The authors of [18] proposed a multiple kernel support vector machine

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