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Local binary circumferential and radial derivative pattern for texture classification

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ABSTRACT

Building discriminative and robust texture representation to deal with the changes of texture appearance is a fundamental issue in texture classification. The Local Binary Pattern (LBP) and its variants gain a lot of attention during the past decade and achieve great success in texture description. However, the current existing LBP-based features which treat LBP as local differential or orientation gradient operator, exploited local orientation pattern or anisotropic structure information separately. In this paper, we investigate the theoretical scheme of local differential approximation on the polar coordinate system in order to build a new LBP-based descriptor which better takes into account both radial plus tangential components and derivative information. First, we present an operator called circumferential derivative (CD) based on the tangential information with different order of derivatives. Then, we present an operator called radial derivative (RD) based on the radial information with different order of derivatives. Both extract complementary information locally around a central pixel. A new descriptor, the local binary circumferential and radial derivative pattern (CRDP) is constructed to fuse both local circumferential and radial derivative features based on different orders as well as a global feature based on global difference (GD) of central pixel's intensity. Extensive experiments on Outex, CUReT, KTH-TIPS and KTH-TIPS2-a texture datasets indicate that the proposed CRDP descriptor is discriminative and robust. The results obtained by the proposed CRDP descriptor outperforms more than twenty recent LBP-based state-of-the-art methods, including the best reported results in the literature for aforementioned texture datasets to the best of our knowledge.

1. Introduction

Texture classification is an important topic in the areas of image processing, computer vision and pattern recognition, and has received a lot of research interest and attention during the past decades. It also has a wide variety of potential applications, such as fabrics inspection, medical image analysis, scene or object recognition, content-based image and video analysis [1], and material classification [2,3].

A systematic overview of widely used texture features and a taxonomy of texture analysis approaches are comprehensively surveyed to categorize the texture features in [4]. During the last decade, a number of discriminative and robust texture feature have been proposed in the literature for texture classification, such as Markov model and wavelet frame based algorithms [5,6], filter banks methods [7–10],sparse sets of local keypoints or affine regions based methods [11,12], fractal analysis based features [13–15], modeling based to present texture signature [16,17] and approaches based on learning texton dictionary [3,18–20]. Dong et al. [21] propose a novel heterogeneous and incrementally generated histogram (HIGH) to model four statistical local features and construct a nonnegative multiresolution vector (NMV) to represent a texture image by concatenating all the HIGHs in all wavelet subbands. Afterwards, a novel texture classification method is proposed to model the texture feature of adjacent shearlet subbands by using linear regression [22].

Specifically, the Local Binary Patterns (LBP) descriptor proposed by Ojala et al. [23] has gained considerable attention due to its good discriminative power and computational simplicity. The famous LBP operator and it's variants have been widely applied in various fields during the past two decades [24,25]. Recently, from perspective of mathematical formulation, histograms of equivalent patterns (HEP) [26] which describes a comprehensive and unifying framework with a clear and unambiguous mathematical

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definition for texture analysis, is proposed to address the challenging issue of defining texture and the division of texture features [4]. Binary gradient contours (BGC) [27] projects grayscale pattern into the 8-tuple binary space by pairwise comparing the periphery of 3× 3 neighborhoods along pre-defined routes (single-loop, double-loop and triple-loop) and has been proved to be more effective and efficient in discriminating texture than LBP feature. Kaya et al. [28] propose local binary patterns by neighborhoods (*nLBP*) to encode the relations between each particular neighbor and it's sequential neighbors with a specified distance parameter, which is similar to the descriptors BGC presented in [27].

Many LBP variants with higher degrees of invariance were used to obtain more discriminative, robust and compact texture representation against the variability of texture appearance. One of the strategies to improve discriminative power of LBP is the combination of several different and complementary types of descriptors. Ojala et al. [23] improved LBP by adding to it the local contrast in LBP/VAR. Guo et al. [29] proposed LBP variance (LBPV) which uses a global matching scheme to characterize the local contrast information into the LBP histogram. Completed modeling of LBP (CLBP) [30] was represented by its joint distribution of three complementary components: central pixel (CLBP_C), the signs (CLBP_S) and the magnitudes (CLBP_M). Completed local binary count (CLBC) [31] further improved CLBP by encoding local texture through counting the number of value 1s in the binary comparison. Liu et al. [32] proposed the extend local binary pattern to combine local binary radial-difference pattern (RD-LBP) and local neighborhood intensities (NI). However, although these methods have good discrimination with combination of complementary features, their higher feature dimensionality will lead to increased computational cost and sensitive to image rotation variations.

Zhang et al. [33] encodes various distinctive spatial relationships in local patches to extract high order derivative patterns information, which has been proved to be discriminative and robust for face recognition. In [34], a local directional derivative pattern (LDDP) are proposed and extended to higher orders differentiation. Inspired by LDDP, Yuan et al. [35] further improved LDDP by jointly take advantage of high order directional derivatives, circular shift sub-uniform and scale space to build textural descriptor. However, these LBP variants only captured derivative or differential information from a single specific orientation without simultaneously exploited circumferential and radial directional derivative pattern information. This will lead to failed to exploit the complementary information and suffer from the lack of discrimination.

A major challenge for texture classification, especially for analyzing real-world textures, lies in the large variety of geometric, stochastic and photometric transformations of texture appearance, e.g. illumination, rotation, scale, contrast and viewpoint changes, but also occlusions and non-rigid deformations. Therefore, constructing powerful texture descriptors which are able to highly distinguish between intrinsic and extrinsic properties of textures attracted widespread interest. This paper focuses on the problem of rotation invariant texture classification by constructing an effective and efficient texture representation.

In order to address the good insights and shortcomings of LBP and it's variants, and to probe the potential theory foundations or cues, there are two fundamentals question this paper try to answer. The first is: what are the clues and basic attributes of texture contents that could be exploited to build discriminative and robust handcraft descriptor for texture classification? The second is: does the effective texture representations based on gradient pattern extracted from Cartesian coordinate plane of texture image deeply reflect the optimal structure properties and dominant pattern information of visual texture?

As it can be seen, almost all LBP-based features work on the Cartesian coordinate system. However, considering the circular neighborhood structure of the LBP operator, it seems interesting to use the polar coordinate system instead. Thus, we adopt circumferential and radial derivatives to approximate gradients along the tangential and radial directions, respectively. The proposed circumferential derivative pattern and radial derivative pattern capture directional gradient information for different values of angles and radial locations. Moreover, the gradient information is approximated by using the Taylor series expansion to represent the joint distribution of circumferential-radial derivative pattern. Thus, the gradient information is approximate by computing at several order both tangential and circumferential derivatives.

The main contributions of this work are highlighted as follows:

- We introduce a polar coordinate gradient description and its discrete approximation with different order of derivatives derived from Taylor series expansion by exploiting tangential and radial gradient information to further enforce the discrimination of LBP-based descriptors. Then, inspiring on the LBP scheme, we propose both local tangential and radial derivative patterns.
- We propose two novel operators for approximating the tangential and radial gradient information, respectively named circumferential derivative (CD) and the radial derivative (RD).
- We investigate the theoretical scheme of local differential approximation to build LBP-based feature. We propose a novel local binary circumferential and radial derivative pattern (CRDP) descriptor to jointly encode tangential and radial gradient information which are derived from differential operators.
- We further extend CRDP to have properties of rotation invariant and multi-resolution and could be integrated with color information or combined with other LBP variants, e.g., orthogonal combination of LBP [36] and BRINT [37].
- The proposed CRDP feature is evaluated on four popular texture datasets. The results show that the CRDP descriptor is discriminative and robust for texture classification, and achieves significant improvements and even better than twenty state-of-the-art descriptors.

The rest of this paper is organized as follows. Section 2 reviews the classical LBP approach and it's variants. Section 3 lays the theoretical foundations of our work. The new CD and RD pattern features based on circumferential-radial derivatives are described in Section 4. Section 5 describes the proposed local binary circumferential and radial derivative pattern (CRDP) feature. Extensive experimental results on several texture datasets are reported in Section 6 where our approach is evaluated by comparing it with other state-of-the-art texture classification methods. Finally, Section 7 concludes the paper with some discussions.

2. A brief review of the local binary pattern (LBP) and it's variants

2.1. Local binary pattern (LBP) descriptor

The original LBP operator, proposed by Ojala et al. [23], processes the pixels of an image densely by comparing the gray values between a given central pixel and its neighbors to form a binary bit string, and then obtains a pattern value by multiplying each binary bit with the corresponding weight and summing them up. Formally, the basic LBP operator at a given center pixel is defined as:

$$LBP_{N,R} = \sum_{n=0}^{N-1} s(g_n - g_c)2^n \quad (1)$$