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Repulsive-and-attractive local binary gradient contours: New and efficient feature descriptors for texture classification

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ABSTRACT

This paper presents new modeling of local binary patterns for texture representation. Referred to as local binary gradient contours (LBGC), the proposed models are expected to better represent the salient local texture structure. Thanks to the flexibility of repulsive-attractive characteristics, which represent the cornerstone of the proposed descriptors, two distinct LBP-like descriptors are built: repulsive and attractive local binary gradient contours (RLBGC and ALBGC). Conventional methods such as LBP, the family of binary gradient contours (BGC1, BGC2 and BGC3), LBP by neighborhoods ($nLBP_d$) and several other LBP-like methods, are based on pairwise comparison of adjacent pixels. Unlike these methods, the proposed RLBGC and ALBGC operators encode the differences between local intensity values within triplets of pixels, along a closed path around the central pixel of a 3x3 gray-scale image patch. In order to increase the robustness of the proposed RLBGC and ALBGC descriptors, the triplet formed by the average local and average global gray levels (ALGL and AGGL) and the central pixel is incorporated in the modeling. In order to make the proposed approach more robust and stable, the RLBGC and ALBGC are concatenated together to form multi-scale repulsive-and-attractive local binary gradient contour (RALBGC) descriptor. Extensive experimental results from 13 challenging representative texture datasets show that the proposed descriptors, applied on each dataset, can achieve interesting classification accuracy, which is competitive or better than a great number of state-of-the-art LBP variants and non-LBP methods. Furthermore, statistical hypothesis testing is performed to prove the statistical significance of the achieved accuracy improvement over all the tested datasets.

1. Introduction

Texture is an important characteristic in visual scenes and contains useful information about the structural arrangement of objects like surface of materials, crops in a field, natural scenes, human skin and many more which are characterized by their own distinct texture. The analysis of this inherent characteristic has been a long-standing research topic due to both the scientific challenge it represents and the important role it plays in a wide variety of computer vision- and image analysis-based applications. Examples of texture analysis-based applications include remote sensing, scene understanding, material classification and recognition, background subtraction, pedestrian detection, face recognition and texture classifica-

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tion. Particularly, this last active research topic, as the most important component of texture analysis aiming at assigning an unseen texture sample to a predefined class, has received considerable attention during the past decades and continues to engage the field of computer vision. It primarily consists of two critical subproblems: feature extraction and classifier designation [28]. Extraction of powerful texture features is the key step in most approaches focusing on texture classification. Indeed, poor extraction of features involves producing poor recognition quality, even when using the best classifiers. Consequently, most studies on texture classification focus on the feature extraction component, and numerous texture feature extraction methods have been developed with excellent surveys given in [19,28]. The performance of a given texture feature is measured through its ability to balance two competing aspects: low computational complexity and high-quality description. Low dimensionality representation and high-speed descriptors are important aspects required for real-time applications. High-quality descriptors require a tradeoff between robustness, due to large intraclass variations caused by variations in illumination, blur, scale, rotation, noise and occlusion, and distinctiveness due to the wide range of texture classes.

Recently, active research on texture classification has focused on pattern-based features, due to their effectiveness and the ease of extracting them from an image. LBP based methods, due to their outstanding performance, have emerged as one of the most prominent texture descriptors. Ojala et al. [26] first proposed a local binary patterns (LBP) operator, known as one of the most successful statistical approaches for texture classification. The LBP operator has been thereafter successfully applied in many research areas such as medical image analysis, outdoor scene analysis, dynamic texture recognition, biomedical image analysis, motion detection, face description and recognition, image retrieval, object detection, remote sensing, fingerprint matching and background subtraction. Since Ojala's work, a variety of LBP variants have been proposed in the literature to improve its discriminative power, robustness, and applicability. Hafiane et al. [14] proposed a median binary pattern (MBP) operator for texture classification. MBP consists of thresholding a whole 3×3 neighbourhood by its median value instead of the value of its central pixel. Heikkilet al. [16] proposed center-symmetric LBP (CS-LBP) which combined the strengths of the well-known SIFT descriptor and LBP texture operator. Tan et al. [35] proposed a local ternary pattern (LTP) for face recognition. LTP, which extends the original LBP to 3-valued codes using a threshold, is more insensitive to noise than LBP, but not strictly invariant to gray-scale changes, and the selection of a suitable threshold value is not easy. Guo et al. [10] developed a completed LBP (CLBP) operator for texture classification. The CLBP descriptor includes information contained in the magnitude of local differences as complementary to the signs of LBP. The LBPV method introduced in [11] consists of incorporating local contrast and global orientation information into the LBP histogram. BGC1, BGC2 and BGC3 operators proposed by Fernndez et al. [8] are based on pairwise comparison of adjacent pixels belonging to one or more closed paths traced along the periphery of a 3×3 neighborhood. Liu et al. [21] proposed four LBP-like descriptors to extract complementary texture information of local spatial patterns, two local intensity-based (CI-LBP and NI-LBP), and two local difference-based (RD-LBP and AD-LBP), and multiscale joint histogram features (NI/CI/LBP, NI/RD/LBP and NI/RD/CI/LBP) are also considered. The authors in [48] proposed multiple local patterns (LMP) to encode textural features. LMP, which considers a neighborhood in the form of a binary and m-ary number, extends binary patterns to multiple patterns. Recently, Kaya et al. [41] proposed local binary patterns by neighborhoods ($nLBP_d$) where the comparison between the peripheral pixels is done with sequential neighbors and/or inside neighbors defined by a distance parameter d. Zhao et al. [46] proposed a local quantization code histogram (LQCH) to validate the performance of different local quantization levels for texture classification. The pixels located in different quantization levels are separately counted and the average local gray value difference is used to set series of quantization thresholds. Yuan et al. [43] proposed high-order local ternary patterns (HLTP) for smoke detection and image classification. Liu et al. [19] proposed a new family of LBP-like descriptors based on local accumulated pixel differences: Angular Differences (AD) and Radial Differences (RD) for face recognition.

Although significant progress has been made and most LBP variants have improved the performance of LBP, there still remains some potential flaws in LBP. Indeed, most extensions of LBP still have prominent limitations and suffer, as will be shown later, from the defects inherent to LBP.

To address the limitations and weaknesses of these methods and retain the simplicity and effectiveness of the traditional LBP, we propose a conceptually and computationally simple yet efficient family of new texture descriptors referred to as repulsive-and-attractive local binary gradient contours (RLBGC, ALBGC and RALBGC) for texture classification. The main advantages of the proposed descriptors are: 1) implementation simplicity; 2) low computational complexity 3) free of tuning parameter setup; 4) high performance compared to old and recent state-of-the-art descriptors; 5) considerable enhancement of both the discriminative power of LPB-like descriptors and their robustness to small variations. Specifically, the major contributions of this work are summarized as follows:

- A formal definition of repulsive-and-attractive binary thresholding functions based on the concept of repulsive-and-attractive local micro-structure, which is an interesting gray-scale local micro-pattern, is introduced. As will be shown later, these functions are able to overcome the inherent defect of LBP.
- Two new LBP-like operators are proposed: repulsive-and-attractive local binary gradient contour descriptors (RLBGC and ALBGC). These operators are more useful for image representation than basic LBP and a large number of old and recent LBP variants and non-LBP methods. Indeed, the proposed descriptors convey valuable information about the nature of textures since they capture local structures.
- Single-scale analysis realized with RLBGC and ALBGC operators is extended to multiscale analysis through concatenation scheme to obtain the RALBGC descriptor, which should be more robust and stable.