Pattern Recognition Letters 74 (2016) 53–60

Contents lists available at ScienceDirect

Pattern Recognition Letters

journal homepage: www.elsevier.com/locate/patrec

Symmetry detection based on multiscale pairwise texture boundary segment interactions☆

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ARTICLE INFO

Article history:
Received 17 August 2015
Available online 15 February 2016

Keywords:
Berkeley Segmentation Dataset (BSDS300)
Hough-style voting approach
Line segment detector (LSD)
Local symmetry detection
Medial axis segment
Pair of lines

ABSTRACT

In this paper, we propose a new unsupervised and simple approach to local symmetry detection of ribbon-like structure in natural images. The proposed model consists in quantifying the presence of a partial medial axis segment, existing between each pair of (preliminary detected) line segments delineating the boundary of two textured regions, by a set of heuristics related both to the geometrical structure of each pair of line segments and its ability to locally delimit a homogeneous texture region in the image. This semi-local approach is finally embedded in a two-step algorithm with an amplification step, *via* a Hough-style voting approach achieved at different scales and coordinate spaces which aims at determining the dominant local symmetries present in the image and a final denoising step, *via* an averaging procedure, which aims at removing noise and spurious local symmetries. The experiments, reported in this paper and conducted on the recent extension of the Berkeley Segmentation Dataset for the local symmetry detection task, demonstrate that the proposed symmetry detector performs well compared to the best existing state-of-the-art algorithms recently proposed in the literature.

1. Introduction

The problem of extracting automatically symmetry axes or contours lying in the middle of elongated structures (also referred to as ribbons or ridges in the literature) from natural image is an important and still difficult mid-level computer vision task. This preprocessing step, amounting to approximate reflective symmetry of each object present in the scene, can thus be the preliminary preattentive and/or useful complementary step of many high-level image understanding algorithms and computer vision systems such as object localization/recognition [7], 3D reconstruction [2], indexing [11], gait analysis [27], human action recognition [33] or motion estimation problems [13,14] to name a few.

The concept of symmetry both plays an important role in human visual and perceptual system (which turns out extremely sensitive to symmetry structures) and is a prolific phenomenon that exists widely in the real world. Indeed, most man-made and biological objects exhibit symmetry to some extent. That is why symmetry is an important mid-level cue, which is receiving a growing attention in image analysis due to its inherent ability to reveal the shapes of salient structures in medical applications [30], and also a powerful concept that facilitates object detection (or localization) and enhance recognition in many image understanding systems in which some prior knowledge of a shape to be recognized can be (jointly or subsequently) included [7,15,35]. In addition, this symmetry-based mid-level cue can be efficiently used as semi-global constraints to low-level image tasks such as segmentation and denoising problems (*e.g.*, by simply favoring label or gray-level homogeneity for pair of sites sharing the same, preliminary detected, axis of symmetry [25] or for regulating a nonlinear diffusion process for adaptive image enhancement and denoising in fingerprint imagery [1]. This symmetry-based cue can also be exploited as a feature to improve a real-time tracking procedure of moving objects [19] such as hand tracking or a hand posture recognition system [3]. Besides, since symmetry cues are one of the possible principles of the Gestalt laws, this mid-level feature could be useful to detect the other high-level cues of the Gestalt laws of perceptual organization. In this work, we aim at extracting local symmetry axes directly from the unsegmented image. By this fact, this work is different from the silhouette-based symmetry detection approach first relying on a reliable map of segmented shapes.

In the case of the symmetry detection directly from the image, a possible approach is to use a global approach, processing the entire image as a signal from which symmetric properties are inferred often *via* frequency or Fourier analysis [16]. However, these

☆ This paper has been recommended for acceptance by Egon L. van den Broek.

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http://dx.doi.org/10.1016/j.patrec.2016.01.014
0167-8655/

global approaches are limited to the detection of a single axis of symmetry and are biased by the background structure of the images.

An alternative to these global approaches consists in exploiting a local pixel or feature-based approach and more precisely, either the idea of quantifying the symmetry contribution of each (preliminary detected) edge points [10] or (its soft version, *i.e.*,) each pair of pixels [31], weighted by their intensity gradient amplitude (in order to favor pairs of edge points belonging to each object contour). In the same spirit, another strategy consists of matching symmetric pairs of feature points (local features such as edge features, contours, boundary points or SIFT/SURF feature points). The "amount" of symmetry exhibited by each pair is quantified by the relative location, orientation and scale of the features in the pair. These pairwise symmetries are then either analytically determined or accumulated in a Hough-style voting space (or in an axis-parameter space) to determine the dominant symmetries present in the image [17,21]. Nevertheless, it is worth mentioning that the reliability of these local features-based techniques suffers if the feature point extraction step fails to generate sufficient number of relevant feature points, which is the case of input images with a smooth image with no texture. Besides, these latter approaches are more suited to detect global reflection symmetries, associated with each whole object present in the scene, rather than local symmetries, associated to each part of an object [28,35].

Finally, another way consists in combining a local and global or a multi-scale approach. In this latter approach, the authors in [29] generalize the medialness notion (which measures the degree of belonging of the point to the medial axis of the object) and defined it as a convolution product of the initial image with a kernel, based on normalized Gaussian derivatives of intensity. In this optic, a recent machine learning framework exploiting local and global spectral features (on several scales) has also been recently proposed in [34] to train a symmetry detector on a symmetry ground truth dataset constructed on top of the well-known Berkeley Segmentation Dataset (BSDS300) [22] and using human-assisted segment skeletonization. The availability of this new dataset (herein further referenced as the LS-BSDS300 for Local Symmetries in the BSDS300) has allowed, up to now, to measure, with good statistical confidence, the performance of several symmetry detectors proposed in the literature. Amongst the methods validated on this new dataset, we can cite the following multi-scale and/or semi-local approaches; Lindeberg [20] introduces a multi-scale ridge detector by combining multiple eigenvalues of the image Hessian. Levinshtein et al. [18] propose to detect partial medial axes after superpixel segmentation and learn an affinity function to perceptually group adjacent superpixels belonging to the same object which will then be approximated by fitting ellipses from which he finally retrieves the major axes. Finally, let us mention the statistical framework proposed in [35] in which the symmetry detection problem is formulated as a spatial Bayesian tracking task using a particle filtering approach and an adaptive semi-local geometric model of ribbons.

In this paper, we propose a semi-local approach which consists in exploiting the idea of quantifying the presence of a local symmetry axis segment existing between each pair of preliminary detected straight line segments delineating the boundary of two textured regions in the scene. This preliminary detection task is efficiently carried out, in our application, by an adaptive, accurate and fast (linear-time) Line Segment Detector (LSD) (introduced by Gioi et al. [9]) and optimal according to the perception-based a contrario (or Helmholtz) principle (which is also adaptive to image content) and followed by a filtering process aiming to select lines that delineates the boundaries between different textured areas. The likelihood of the presence of a partial medial axis segment, exhibited by each pair of lines, is estimated from a set of heuristics related both to the geometrical structure of each pair of lines and its ability to locally delimit a homogeneous texture region in the image. This semi-local approach is finally embedded in a two-stage algorithm with an amplification procedure combining both a Hough-style [8] voting scheme, achieved in different coordinate spaces, and a denoising step based on an averaging technique. The Hough-like voting scheme aims at determining the dominant local symmetries present in the image while the averaging procedure helps to remove noise and spurious local symmetries.

Fig. 1. From lexicographic order: original image number 134052 of the BSDS300 and Line Segment Detection ($N_L = 70$ detected straight line segments) at three different resolution levels (namely {0.25, 0.625, 1.0} filtered by the proposed soft edge potential map in the texture sense in order to detect only line segments that delineate the boundaries between different textured areas.

2. Proposed model

2.1. Texture boundary segment extraction step

Our symmetry detection approach relies mainly, first, on the reliable extraction, at different resolution scales, of the different line segments existing in the image. More conceptually, this preliminary step thus relies on the fact that man-made objects and many shapes accept an economic description in terms of straight lines. In addition, this representation style, in terms of main straight lines, is also interesting due to its appealing ability to abstract away unwanted (or useless) details, to clarify or simplify shapes and to focus on relevant features while allowing to offer a compact representation of the geometric content of the scene with few line segments [23]. To attain this goal, we rely on the fast Line Segment Detector (LSD) recently introduced in [9] which is a linear-time line segment detector that gives sub-pixel accurate detection results of a controlled pre-determined number of false detections according to the *a contrario* principle. It is worth mentioning that our symmetry detection procedure remains independent of the choice of the underlying line detector as far as the latter turns out both, as the LSD detector, reliable and fast. Indeed, in contrast to classic edge detector, this algorithm defines a line segment as a rectangular region whose points share roughly the same image gradient orientation (within a certain tolerance). In addition, the LSD algorithm has the appealing property to achieve a line segment detection for a given resolution level of the input image[1] (see Fig. 1). This multiscale analysis capability of the LSD algorithm will be fully exploited in our symmetry detection approach. This algorithm is very efficient to detect line segments based on the empirical discovery made by Burns et al. [4] showing that connected

[1] The scale of analysis is a choice left to the user and thus an (interesting and important) internal input parameters of the LSD algorithm. More precisely, in the LSD algorithm, this scaling is performed by a Gaussian sub-sampling (the image is in fact filtered with a Gaussian kernel to avoid aliasing and then sub-sampled).