Physica A 440 (2015) 9–18

Contents lists available at ScienceDirect

Physica A

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

Image edge detection based on local dimension: A complex networks approach

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HIGHLIGHTS

- A novel method is proposed for modeling the image to complex network.
- The proposed method based on local dimension is to address edge detecting.
- It is observed that edge pixels have lower node dimension than non-edge pixels.

ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 26 May 2015
Available online 28 July 2015

Keywords:
Complex networks
Edge detection
Local dimension
Image processing

ABSTRACT

A novel approach based on local dimension of complex networks is proposed to address edge detecting issue in image processing. A new method that the image was modeled to complex networks is proposed. Our method for mapping an image into complex network is based on the weighted combination of the Euclidean distance and gray-level similarity indices, which differs from the way was done previously in several works. The local dimension of node characters the local property of pixel. It is observed that edge pixels obviously have lower node dimension than non-edge pixels, which is used in our proposed edge detection method. The proposed method is applied to both synthetic and natural images. The results show the efficiency of our proposed method.

1. Introduction

A revolution of natural science methodology was caused by the rise of complexity science in recent years [1,2]. With the development and application of nonlinear science, complex networks is becoming an burgeoning and overwhelming subject of scientific research over the years [3–9]. Complex networks is an effective mathematical model to explore complexity. The influence of complex networks is currently pervading all kinds of sciences, ranging from physical, technological, biological, to social sciences [3,4,10–14].

The main research interests of image processing in the context of networks is the node dynamics but not the network topology. In the context of node dynamics, typical examples are cellular neural networks (CNN) [15,16] and pulse coupled neural network (PCNN) [17]. PCNN has been widely applied in image segmentation [18], image fusion [19], image thinning [20] and so on [21]. However, only recently the network topology has been considered in the application of image processing. A number of complex network-based approaches have been introduced in recent years. Approaches based on optimization by graph-cut such as Graph cuts [22] and GrabCut [23] have been developed for solving the problem of

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http://dx.doi.org/10.1016/j.physa.2015.07.020
0378-4371/

efficient, interactive foreground/background segmentation. A methodology was introduced to shape boundary characterization [24], where a shape is modeled into a small-world complex network [9]. An approach was proposed for shape characterization [25], which combines modeling shape into a complex network and the analysis of its complexity in a dynamic evolution context. A complex network-based approach was proposed for texture analysis and classification [26]. The work investigated how a texture image can be effectively represented, characterized and analyzed in terms of a complex network. The research technique in complex networks is also used in image encryption too [27]. In the field of image processing, the advantage of complex network-based approaches includes robustness, noise tolerance, scale invariance, rotation invariance and so on. What is more, there are some interesting work on image representation as a complex network and image characterization in term of topological measurements [28]. However, few researches of the local dimension of complex networks have been considered to address the issue in edge detection.

Edge detection is a long-standing problem in digital image processing and computer vision [29–37]. A variety of edge detection theories and algorithms are proposed unceasingly during past decades [38–40]. A large number of edge detection operators is designed to be sensitive to certain types of edges. Most of the existing methods for edge detection can be grouped into two categories, Gradient and Laplacian operators [29]. There are other edge detection methods such as snake methods [41] and mathematical morphology [42]. Methods based on Gradient operators mainly include the Roberts operator [43], the Prewitt operator [44] and the Sobel operator [45]. Methods based on Laplacian operators mainly include Laplacian of Gaussian Method [46] and Canny edge detector [47]. Both gradient-based and Laplacian based edge detection methods have some disadvantages such as noise sensitivity, illumination sensitivity, non-adaptive parameters and so on [29]. However, researching on edge detection from the perspective of complex networks can weaken the disturbance from noise, illumination and so on and compensate the disadvantage of non-adaptive parameters partly. Edge detection based on complex networks is to target the correlation of pixels instead of gradient or Laplacian.

In this work, a novel edge detection approach based on local dimension of complex networks [48] is proposed. First of all, a new method to transfer an image into complex network is proposed. The way that the image was modeled to complex networks is based on the weighted combination of the Euclidean distance and gray-level similarity indices, which differs from those was done previously in several works. Then, node dimensions are measured by characterizing the local dimension of nodes. It is observed that edge pixels obviously have lower node dimension than non-edge pixels. On the basis of the difference, edge pixels and non-edge pixels are classified therefore edges are extracted. Moreover, comparison and analysis between some present edge detection method and our proposed approach is made. The results of simulation show that this proposed approach can efficiently detect the edge by node dimension. Comparison is made between Sobel operator [45], Laplacian of Gaussian Method [46], Canny edge detector [47] and the proposed approach. The results show the efficiency of our proposed method.

The main contribution of this work is that a new model based on the Euclidean distance and gray-level similarity indices is proposed to convert image into complex networks, the conception of node dimension is proposed according to the local dimension of complex networks, it is observed that edge pixels obviously have lower node dimension than non-edge pixels, and it has an interesting contribution to edge detection.

The remainder of this paper is structured as follows. Section 2 includes some preliminaries on complex network and edge detection. In Section 3 our proposed method for mapping an image into complex network is proposed. Section 4 includes the description and results of the calculation of node dimension and edge detection of our proposed approach. Section 5 includes the comparison and analysis between some present edge detection method and our proposed approach. Conclusions are drawn in Section 6.

2. Preliminaries

2.1. Complex networks and edge detection

In the context of network theory, a complex network is a graph (network) with non-trivial topological features and dynamic characteristics that do not occur in simple networks such as lattices or random graphs but often occur in graphs modeling real systems. In order to research the complexity of real systems or solve complex problems, complex systems are considered in the context of complex networks usually. In general units and their connections of a system are regarded as nodes and edges in a graph respectively.

A digital image is a two-dimensional lattice consisted of pixels essentially. Edge detection serves to simplify the analysis of images by reducing the amount of non-edge pixels, while at the same time preserving edge pixels about object boundaries. A body of researches on edge detection concentrate on detecting pixels intensity changes. Many mathematical methods are based on the gradient magnitude, using the local directional maxima of the gradient magnitude as an estimation of the local orientation of the edge. In this way, intensity changes are best detected by searching for zero crossing in the Laplacian or other non-linear differential expression. However, intensity in natural images always emerge obviously and changes over a wide range of scales. Moreover, many factors make edge detection to be a non-trivial task such as noise pollution, illumination variation, background clutter and so forth.

Edge detection can be considered in the context of complex networks. Predecessors have made many contributions on image processing from the perspective of networks [49–52]. Although methods to transfer image into complex network have been done previously in several works, the ways are different. In our work, a digital image is converted into complex