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Binary image denoising using a quantum multilayer self organizing neural network

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ABSTRACT

Several classical techniques have evolved over the years for the purpose of denoising binary images. But the main disadvantages of these classical techniques lie in that an *a priori* information regarding the noise characteristics is required during the extraction process. Among the intelligent techniques in vogue, the multilayer self organizing neural network (MLSONN) architecture is suitable for binary image preprocessing tasks.

In this article, we propose a quantum version of the MLSONN architecture. Similar to the MLSONN architecture, the proposed quantum multilayer self organizing neural network (QMLSONN) architecture comprises three processing layers viz., input, hidden and output layers. The different layers contains *qubit* based neurons. Single *qubit* rotation gates are designated as the network layer interconnection weights. A quantum measurement at the output layer destroys the quantum states of the processed information thereby inducing incorporation of linear indices of fuzziness as the network system errors used to adjust network interconnection weights through a quantum backpropagation algorithm.

Results of application of the proposed QMLSONN are demonstrated on a synthetic and a real life binary image with varying degrees of Gaussian and uniform noise. A comparative study with the results obtained with the MLSONN architecture and the supervised Hopfield network reveals that the QMLSONN outperforms the MLSONN and the Hopfield network in terms of the computation time.

1. Introduction

It has always been a challenging task for the computer vision research community to extract objects faithfully from a noisy perspective. In recent years the growth and use of digital images has seen dramatic proportions. However, only a small portion of these images are relevant or contains the necessary information. The nontrivial contents, usually in the form of interesting objects, are sufficient to represent the semantic meanings in most cases and consequently play an important role in many image applications such as content-based retrieval. Therefore, several classical techniques have evolved over the years targeted in this direction. For example, graph-theoretic approaches [1,2] make use of energy function optimization to solve the extraction problem; edge-linking methods [3] connect a subset of the fragments produced by edge detection to form a closed contour for the interesting object, etc. Although these approaches work well in some cases, the tendency to solve the extraction problem with little consideration of human visual perception makes them to have undesirable performance under some complicated conditions such as in cluttered or noisy images. An effort has been made in this article to denoise binary images from varied noisy perspectives taking into consideration the human visual perception in the form of the nature of noises encountered. The technique employed resorts to a soft computing paradigm inspired by the quantum mechanical principles to achieve robustness and time efficiency.

The article is organized as follows. Section 2 provides an in-depth survey on the related works pertaining to object extraction and image denoising available in literature. The focus of research work of this article is mentioned in Section 3. Section 4 elucidates the requisites of the basics of quantum computing relevant to this article. The principle of operation of the multilayer self organizing neural network architecture (MLSONN) [27] is highlighted in Section 5. Section 6 provides an insight into the perspectives of the supervised Hopfield network. Section 7 introduces the proposed quantum multilayer self organizing neural network architecture (QMLSONN) architecture. It also discusses the dynamics of operation and the corresponding network weight adjustment procedures of the network architecture. The experimental results of application of the proposed QMLSONN, MLSONN [27] and the Hopfield [24]

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network architectures on Gaussian and uniform noise affected artificial and real life binary images are illustrated in Section 8. Section 9 concludes the article with future directions of research.

2. Review of literature

Among various extraction approaches, saliency-based ones perform better as they well accord with human visual perception. Itti et al. [4] combined multiscale features into a single topographical saliency map and adopted a dynamical neural network to select the attended areas that roughly contained the interesting objects. Ma and Zhang [5] generated a contrast-based saliency map and extracted objects by fuzzy growing. Achanta et al. [6] outputted a frequency-tuned saliency map and binarized it with an adaptive threshold. Hou and Zhang [7] constructed the saliency map by analyzing the log-spectrum of the image and used a simple threshold to detect pro-objects. However, nearly all existing saliency-based approaches suffer from the integrity problem, viz., the extracted result is either a small part of the object (referred to as sketch-like) or a large region that contains some redundant part of the background (referred to as envelope-like). Yu et al. [8] proposed an automatic object extraction technique using complementary saliency maps. In this approach, they integrated two kinds of "complementary" saliency maps (i.e., sketch-like and envelope-like maps). Hence, the extraction process is decomposed into two sub-processes, one used to extract a high-precision result based on the sketch-like map, and the other used to extract a high-recall result based on the envelope-like map. Then a classification step is used to extract an exact object based on the two results to do away with the integrity problem.

Other efforts in this direction rests on the use of wavelets for the purpose of image denoising and compression [9–11]. Among the filtering approaches, several efforts have also been invested. Smolka et al. [12] proposed a novel approach to the problem of impulsive noise removal in color digital images. The proposed switching filter is based on the rank weighted, cumulated pixel dissimilarity measures, which are used for the detection of image samples contaminated by impulsive noise process. The introduced adaptive design enables the filter to tune its parameters to the amount of impulsive noise corrupting the image. The comparison with existing denoising schemes shows that the new technique more efficiently removes the impulses introduced by the noise process, while better preserving image details. An important feature of the new filter is its low computational complexity, which allows for its application in real-time applications. Letexier and Bourennane [13] proposed a generalized multidimensional Wiener filter (MWF) for denoising of hyperspectral images (HSIs) by considering the multidimensional data as a third-order tensor. MWF needs to flatten the tensor for attaining the best results. However, flattening is always orthogonally performed, which may not be adapted to data. They estimated the relevant directions of tensor flattening that may not be parallel either to rows or columns. When rearranging data so that flattening can be performed in the estimated directions, the signal subspace dimension is reduced, and the signal-to-noise ratio is improved. They adapted the bidimensional straight-line detection algorithm that estimates the HSI main directions, which are used to flatten the HSI tensor. But the main disadvantages of these classical techniques lie in that an *a priori* information regarding the noise characteristics is required during the extraction process. As a result, a plethora of intelligent efforts has been invested to do away with the flaws and failings of the classical techniques.

Neural networks have often been employed by researchers for dealing with the daunting tasks of extraction [14–16], classification [17–19] of relevant object specific information from redundant image information bases and identification and recognition of objects from an image scene [20–22]. Several neural network architectures, both self-supervised and unsupervised, are reported in the literature, which have been evolved to produce outputs in real time.

Kohonen's self-organizing feature map [23] is centered on preserving the topology in the input data by subjecting the output data units to certain neighborhood constraints. The Hopfield's network [24] proposed in 1982, is a fully connected network architecture with capabilities of auto-association. A photonic implementation of the Hopfield network is also reported in [25], where a winner-take-all algorithm is used to emulate the state transitions of the network.

Several attempts have also been reported in [26] where self organizing neural network architectures have been used for object extraction and pattern recognition. Several neighborhood based network architectures like the multilayer self organizing neural network (MLSONN) [27] are used for similar tasks. The underlying approach is centered on employing a fully connected multilayer network architecture with each neuron of one layer connected to its neighboring neurons in the previous layer. Such a network architecture, upon stabilization leads to the detection and extraction of objects by means of self supervision of inputs. The MLSONN [27] architecture is a feedforward network architecture and resorts to some fuzzy measures of the image information so as to derive the system errors therein. A generalized self-organizing multilayer neural network incorporating fuzziness measures is designed in [28] for object extraction. Results of a simulation study using synthetic and real images are seen to be quite satisfactory.

Bhattacharyya et al. [29] proposed a novel neural network architecture suitable for image processing applications. The proposed architecture referred to as the bi-directional self-organizing neural network (BDSONN) architecture, comprises three interconnected fuzzy layers of neurons and it is devoid of any back-propagation algorithm for weight adjustment. The fuzzy layers of neurons represent the fuzzy membership information of the image scene to be processed. One of the fuzzy layers of neurons acts as an input layer of the network. The two remaining layers viz. the intermediate layer and the output layer are counterpropagating fuzzy layers of neurons. These layers are meant for processing the input image information available from the input layer. The constituent neurons within each layer of the network architecture are fully connected to each other. The intermediate layer neurons are also connected to the corresponding neurons and to a set of neighbors in the input layer. The neurons at the intermediate layer and the output layer are also connected to each other and to the respective neighbors of the corresponding other layer following a neighborhood based topology. The proposed architecture uses fuzzy membership based weight assignment and subsequent updating procedure. Some fuzzy cardinality based image context sensitive information are used for deciding the thresholding capabilities of the network. The network self organizes the input image information by counter-propagation of the fuzzy network states between the intermediate and the output layers of the network. The attainment of stability of the fuzzy neighborhood hostility measures at the output layer of the network or the corresponding fuzzy entropy measures determine the convergence of the network operation. The network is found to outperform the MLSONN architecture [27] in terms of the quality of the objects extracted from noisy perspective. A color version of the same architecture to operate on pure and true color images has been proposed by Bhattacharyya et al. in [30]. The proposed architecture is referred to as the PBDSONN architecture, It outperforms the parallel version of the MLSONN architecture as well.

Quantum computation has evolved from the theoretical studies of Feynman, Deutsch and others, to an intensive research field since the discovery of a quantum algorithm which can solve the problem of factorizing a large integer in polynomial time by Shor (1994). Matsui et al. [31] proposed a Qubit Neuron Model which