Signal Processing: *Image Communication* 29 (2014) 1149–1157

Contents lists available at ScienceDirect

Signal Processing: *Image Communication*

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

Blind image quality assessment using a reciprocal singular value curve

Qingbing Sang [a,1], Xiaojun Wu [a,*], Chaofeng Li [a], Alan C. Bovik [b]

[a] Key Laboratory of Advanced Process Control for Light Industry (Ministry of Education), School of Internet of Things Engineering, Jiangnan University, Wuxi 214122, China

[b] Laboratory for Image and Video Engineering (LIVE), The University of Texas at Austin, Austin, TX 78712, USA

ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form
12 September 2014
Accepted 17 September 2014
Available online 28 September 2014

Keywords:
Image quality assessment
Singular value decomposition (SVD)
Reciprocal singular value curve
No-Reference

ABSTRACT

The reciprocal singular value curves of natural images resemble inverse power functions. The bending degree of the reciprocal singular value curve varies with distortion type and severity. We describe two new general blind image quality assessment (IQA) indices that respectively use the area and curvature of image reciprocal singular value curves. These two methods almost require very little prior knowledge of any image or distortion nor any process of training, and they can handle multiple unknown distortions, hence they are no-training methods. Experimental results on five simulated databases show that the proposed algorithms deliver quality predictions that have high correlation with human subjective judgments, and that are competitive with other blind IQA models.

1. Introduction

An increasingly large number of digital images are being produced by professional and casual users as digital cameras have become ubiquitous in smartphones, tablets, and stand-alone units. Since in nearly every instance it is desirable to produce clear, crisp images free of excessive noise, annoying blur or other artifacts, the development of methods for automatically assessing the perceptual quality of digitally acquired images has become an important goal of model and algorithm developers [1]. Such tools would greatly facilitate the sorting and culling of the large volumes of images that are so easily obtained. Current objective image quality assessment (IQA) methods fall into three general categories: Full Reference (FR), Reduced Reference (RR) and No Reference (NR) or Blind [2]. FR and RR models require that all or part of the information about the reference image be available. However, in most application scenarios information regarding a reference image is inaccessible. Hence effective NR models may ultimately prove to be more viable.

Existing NR IQA models can be roughly divided into two categories: distortion-specific and general purpose. Distortion-specific models are specialized for a single type of distortion, for example, [3–6] are designed to assess blur distortion, while [7,8] are dedicated to measuring the perceptual severity of JP2K distortions. These models are effective in specific settings. By contrast, general purpose models are intended to handle multiple, possibly unknown distortions.

In recent years, several general purpose NR IQA algorithms have been proposed. These models can further be subdivided into two categories. State-of-the-art learning-based general purpose NR IQA algorithms include GRNN [9], DIIVINE [10], CORNIA [11], BLIINDS-II [12] and BRISQUE [13]. Using a neural network, the authors of [9] proposed a novel NR IQA algorithm that was trained on the local mean, entropy and gradient extracted from the distorted image as well as its phase congruency (PC) map. Based on perceptually

* Corresponding author.
E-mail addresses: sangqb@163.com (Q. Sang), xiaojun_wu_jnu@163.com (X. Wu), bovik@ece.utexas.edu (A.C. Bovik).
[1] Tel.: +86 13812267640.

http://dx.doi.org/10.1016/j.image.2014.09.005
0923-5965/

relevant natural scene statistics (NSS) models, the authors of [10] first proposed a new two-step framework named blind image quality index (BIQI) [14], then later refined these to create the Distortion Identification-based Image Verity and Integrity Evaluation (DIIVINE) index. The authors of [11] present an efficient unsupervised NR IQA framework. They use raw image patches extracted from a set of unlabeled images to learn a dictionary in an unsupervised manner. BLIINDS-II [12] introduces a generalized parametric model of the natural statistics of local image discrete cosine transform (DCT) coefficients to predict image quality scores. The BRISQUE model [13] deploys a space-domain NSS model from
which quality-predictive features are derived. The above-mentioned NR IQA algorithms are generally based on machine learning principles, and hence require conducting training on and testing against human opinion scores of distorted images. Of course, learning-based models can only reliably assess quality degradations arising from the distortion types that they have been trained on, potentially limiting their utility. In many practical situations there is no available information of new or varying distortions, hence it is highly desirable to create algorithms that reduce or eliminate this dependence.

In order to overcome the disadvantages of learning based IQA methods, a number of unsupervised, training free NR IQA models have been proposed. In [15], the authors proposed an NR IQA model that operates by seeking latent quality factors. A newer IQA model, called the natural image quality evaluator (NIQE) [16] is based on the construction of a “quality aware” collection of perceptually relevant statistical gradient and phase congruency features based on a simple and successful space domain NSS model. This model does require a corpus of pristine images from which to estimate the model parameters. In [17] the authors proposed a quality-aware clustering (QAC) method which learns a set of centroids at each quality level. This method does not require human Mean Opinion Scores (MOS), but it does require distorted images to learn from. In [18], the authors proposed a no-training method which using a simple functional relationship of perceptually relevant image features to predict image quality. The limitation of the algorithm is that a classification algorithm is needed to distinguish noise distortion from other distortion categories. Here we develop an alternative general purpose NR IQA algorithm that also is able to predict the perceptual severities of multiple kinds of distortions without any training on human scores. This new ‘completely blind’ IQA model uses very simple features derived from a ‘reciprocal singular value curve’ computed from the image. The new model is tested on five IQA databases and is shown to deliver highly competitive performance against other NR IQA models and even against widely-used FR IQA algorithms.

The rest of the paper is organized as follows. Section II analyzes the relationship between image quality and the reciprocal singular value curve. Section III presents the framework of the new image quality model. Experiments conducted on five public IQA databases are presented and analyzed in Section IV. Section V concludes the paper.

2. Relationship between image quality and singular values

2.1. A. Brief review of singular value decomposition

Every gray scale image can be considered to be a matrix. Any $m \times n$ real matrix A can be decomposed into a product of three matrices, i.e., $A = USV^T$, where U and V are orthogonal matrices,$U^TU = V^TV = I$ and $S = \begin{bmatrix} S_r & 0 \\ 0 & 0 \end{bmatrix}$, where $S_r = diag(\sigma_1, \sigma_2, \ldots, \sigma_r), S_1 = (\sigma_1, \sigma_2, \ldots, \sigma_r)$, where r is the rank of A. The diagonal entries of S are the singular values of A, the columns of U are the left singular vectors of A, and the columns of V are called the right singular vectors of A. This decomposition is the Singular Value Decomposition (SVD) of A. This useful tool of linear algebra has been applied to numerous image processing problems including image denoising, compression, watermarking, etc.

The singular value decomposition (SVD) has previously been successfully applied to the FR IQA problem. Existing FR IQA methods that use SVD can be divided into two categories. The first uses only the first singular value to assess image quality. For example, the MSVD algorithm proposed in [19] uses the degree of change of the singular value of the distorted image relative to the singular value of the reference image as the image quality evaluation criteria. The second category also uses the left and right singular vectors to assess image quality [20]. Here we conduct a more detailed study of the behavior of singular values on distorted images and use this to develop an NR IQA model. We find that a simple ‘reciprocal singular value curve’ supplies adequate ‘distortion aware’ information to construct a blind image quality assessment model.

2.2. B. Image quality analysis using a reciprocal singular value curve

In order to demonstrate the relationship between image distortion and singular values, we arbitrarily selected a source image and four blurred versions of it from the CSIQ database [21], as shown in Fig. 1. The images are displayed by order of blur degree. The singular value decomposition was applied to each of the blurred images yielding singular vectors from each. The singular values are plotted against the index of the singular vector for each image, as depicted in Fig. 2. Similarly, we selected another source image and for each of four different distortion types, produced four distorted images suffering from different degrees of distortion. The four distortions are JPEG, JP2K, additive white Gaussian noise and a contrast artifact. We applied the singular value decomposition for each, producing the corresponding singular curves shown in Fig. 3.

From Figs. 2 and 3, it may be observed that the slope of the curve becomes increasingly gentle with larger degrees of distortion with the exception of additive noise. We have observed this behavior over all of the images we have tested. The shape of the curve can be accurately fitted by