J. Vis. Commun. Image R. 25 (2014) 1625–1630

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

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

No-reference image blur index based on singular value curve

Qingbing Sang [a,*], Huixin Qi [a], 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 13 July 2013
Accepted 7 August 2014
Available online 20 August 2014

Keywords:
No-reference blur index
Image quality assessment
Singular value decomposition
Singular value curve
Blind
Image quality
Objective
Perception

ABSTRACT

We describe a new no-reference blur index for still images based on a singular value curve (SVC). The algorithm is composed of two steps. First, the singular value decomposition is performed on the image to be blur-assessed. Then an image blur index is constructed from the singular value curve. Experimental results obtained on four simulated blur databases and on the Real Blur Image Database show that the proposed SVC algorithm achieves high correlation against human judgments when assessing the blur distortion of images.

1. Introduction

Digital images are being produced in vast numbers as digital cameras and camera-equipped smartphones are becoming very widely used. Many of these images are acquired under less than ideal conditions, often by inexperienced or inexpert users. One very common problem is image blur induced by, for example, camera shake or inaccurate focussing, since users routinely capture many more images than in the film days. Since these images are available for digital analysis, it is highly desirable to be able to assess automatically their perceptual quality. Since it would be very valuable to be able to sort and/or cull the 'good' from the 'bad', in recent years research on no-reference (NR) image blur assessment method has become very active. A variety of no-reference blur indexes have been proposed in the literature. For example, in [1], an image sharpness index is proposed that is based on the notion of just noticeable blur (JNB). The authors of [2] proposed a new sharpness measure utilizing local phase coherence (LPC) evaluated in the complex wavelet transform domain. In [3], the authors presented a no-reference image blur metric which utilizes a probabilistic model to estimate the probability of detecting blur at each edge in the image, where the information is pooled by computing the cumulative probability of blur detection (CPBD). Li et al. [4] proposed a new no-reference blur index for still images that is based on the observation that it can be difficult to distinguish between versions of an image blurred to different degrees (BC).

The singular value decomposition (SVD) method is a flexible image matrix decomposition that has been successfully applied to the full reference (FR) image quality assessment (IQA) problem. Existing FR methods based on SVD can be divided into two categories. One directly uses the singular values to assess image quality. For example, the MSVD algorithm proposed in [5] uses the amount of change of the singular value as the image quality evaluation criteria. The other uses the left and right singular vectors to assess image quality [6]. In our approach, we broaden the SVD IQA idea by analysing the distribution of singular values. A new blind method for assessing image blur severity is developed based on a computed singular value curve.

The remainder of this paper is organized in the following way. Section 2 describes the relationship between blur distortions and the image singular value curve. Section 3 details a new no-reference image blur index that uses a model of the singular value curve. The results of experiments conducted on the five databases are presented and analysed in Section 4. Section 5 concludes the paper.

2. The relationship between blur distortion and singular value curve

Every $m \times n$ real grey scale image A can be decomposed into a product of three matrices, $A = USV^T$, where U and V are orthogonal matrices $U^TU = I$, $V^TV = I$, and $S = \begin{bmatrix} S_r & 0 \\ 0 & 0 \end{bmatrix}$, $S_1 = (\sigma_1, \sigma_2, \ldots, \sigma_r)$, where r is the rank of A. The diagonal entries of S are the singular

* Corresponding author.
E-mail addresses: sangqb@163.com (Q. Sang), bovik@ece.utexas.edu (A.C. Bovik).

http://dx.doi.org/10.1016/j.jvcir.2014.08.002
1047-3203/

values of A, S_1 is the singular value vector, the columns of U are the left singular vectors of A, and the columns of V are the right singular vectors of A. This decomposition is the singular value decomposition (SVD) of A.

To explain our idea of SVD-based NR IQA, we arbitrarily selected a source image and its five blurred versions from the CSIQ database [7] and LIVE2 database [8], as shown in Figs. 1 and 3. The degree of blur is sorted in ascending order from images Aa to Ae.

We subjected each of these images to singular value decomposition to obtain singular vectors S_1. A blur-dependent singular value curve is plotted with the singular value along the Y-axis and the index of the singular value vector (the position of the singular value component in the vector) along the X-axis, as shown in Figs. 2 and 4. It can be seen from the singular value curve that the singular values decay exponentially. Note that the curve becomes increasingly steep with larger degree of blur. We plotted the singular value curves of all of the blurred images in the CSIQ database and the LIVE2 database and found that the same law applied.

The matrix norm that we deploy is the Frobenious norm (F-norm), which captures image energy:

$$E = \|A\|_F = \|U * S * V^T\|_F = \|S\|_F = \sqrt{\sum_{i=1}^{r}\sigma_i^2} \tag{1}$$

where r is the matrix rank and the σ_i are singular values. Generally, a sharp image will have Frobenious higher energy value than a blurred counterpart of it.

3. Constructing a no-reference blur index based on a singular value curve

We have found that the shape of the singular value curve of naturalistic images, as exemplified in Figs. 2 and 4, closely resembles an inverse power function. Let $y = S_1(i)$, $x = i$, which we approximate by the following equation

$$y = x^{-q} \tag{2}$$

where y is the singular value $S_1(i)$, and x is the corresponding subscript i of the singular value vector. Because the steepness of the singular value curve corresponds to blur degree, we use q to capture the image blur. Taking logarithms

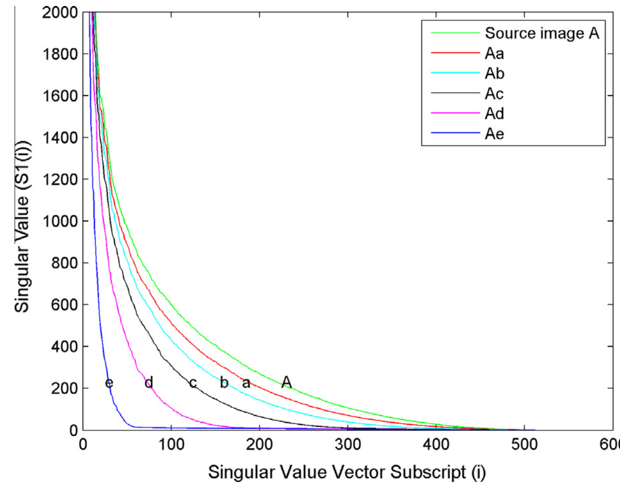

Fig. 2. Singular value curve of Fig. 1.

$$\ln(1/y) = q \ln x \tag{3}$$

and letting $M = \ln(1/y)$, $N = \ln x$, yields

$$M = qN \tag{4}$$

which is a linear equation in the coefficient q which can be solved by linear regression. We use least squares to minimize the residual sum of squares:

$$\min \sum_{i=1}^{r} e_i^2 = \sum_{i=1}^{r}(M_i - qN_i)^2 \tag{5}$$

Setting the derivative of Eq. (3) to zero, we get:

$$\sum_{i=1}^{r} 2(M_i - qN_i)(-N_i) = 0 \tag{6}$$

So the coefficient q can be obtained as

$$q = \frac{\sum_{i=1}^{r} N_i M_i}{\sum_{i=1}^{r} N_i^2} \tag{7}$$

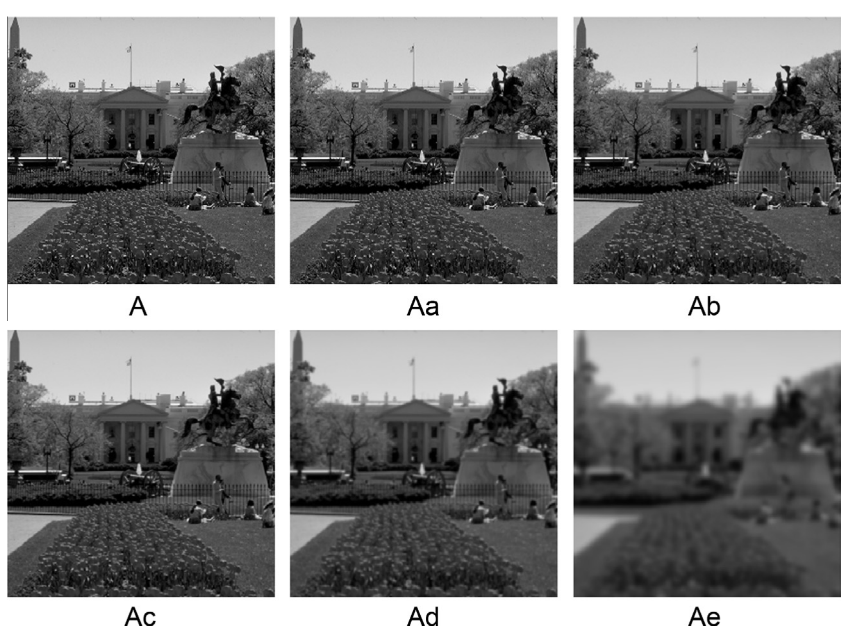

Fig. 1. Source image A and its five increasingly blurred versions in CSIQ database, the degree of blur is sorted in ascending order from images Aa to Ae.