INTRODUCTION

Development of image metrics is important for the objective analysis of image resampling, deringing, deblurring, denoising and other image enhancement algorithms. Common scheme to estimate the quality of an image enhancement algorithm uses a set of artifact free reference images. These images are corrupted to simulate the effect which is aimed to be suppressed by the being analyzed image enhancement algorithm. Then the corrupted images are restored using the given algorithm and compared to the corresponding reference images using image metrics. There exists large variety of image metrics [1] ranging from simple but fast approaches like MSE, PSNR to more sophisticated metrics based on the modeling of the human visual system [2].


Most of image metrics can provide an estimation of perceptual image quality but they cannot be used to develop effective image enhancement algorithms. Two image enhancement algorithms can give the same metrics values but the results can be very different if the first algorithm processes edges well and corrupts non-edge area while the second one corrupts only edges. Such an example for image deblurring is shown in Fig. 1.

Typical artifacts of image enhancement algorithms are blur and ringing effect near sharp edges. The origin of these artifacts is the loss of the high frequency information during image corruption and inaccurate reconstruction of the high frequency information by image enhancement algorithms. Using parameters of image corruption and image enhancement method, it is possible to find the areas related to these artifacts and to calculate image quality metrics in these areas separately. This information can be helpful to find the most problem areas of a certain image enhancement algorithm.

In this paper, we develop a method to find the areas related to two typical image artifacts: edge blur and ringing effect. An algorithm to find the area related to ringing effect is proposed in [5], but this algorithm has limitations and cannot be applied for most of image enhancement algorithms. Our proposed method is based on the concept of basic edges—sharp edges which are distant from other edges thus surviving after image corruption. The perceptual metrics for these areas are suggested.

The proposed metrics estimate the quality of different image enhancement methods by analyzing the image quality in the areas of blur and ringing effect. Image degradation type and its parameters are supposed to be known.

In Section 1, we analyze blur and ringing effect for image enhancement of low-resolution images, blurred images and images with ringing effect. In Section 2, we find the edges suitable for image quality estimation. In Section 3, we introduce our metrics to estimate the quality of image enhancement methods. Application of the proposed metrics to image resampling and image deblurring is shown in Section 4.

1. ARTIFACT ANALYSIS

Since both blur and ringing effect are the results of the loss of high frequency information, these effects should be considered together. If all frequencies above
Hz are truncated in Fourier transform, ringing oscillations appear and edges are blurred. The length of single ringing oscillation and edge width are equal to \( p \) pixels. The example of high frequency truncation is shown in Fig. 2. Although the number of ringing oscillations is unlimited for the high frequency cut off, usually no more than 1–2 oscillations are noticeable.

We will call parameter \( p \) as the cut off parameter.

In practice, the high frequency information is usually corrupted but not completely absent, and the cut off frequency cannot be obtained directly from Fourier transform. In this case additional investigations are required to estimate blur and ringing effect parameter.

We can also predict the parameter’s value from the image degradation type a priori.

Low-resolution images are constructed using downsampling procedure which includes low-pass antialiasing filtering followed by the decimation procedure. During the decimation with scale factor \( s \), the frequencies greater than \( \frac{1}{2s} \) are discarded. The cut off is not ideal because of the two-dimensionality of the image. For any linear image resampling method producing blur and ringing effect, the parameter \( p \) depends only on scale factor \( s \) and \( p = s \). For non-linear image resampling methods we use \( p = s \) too.

In image deringing the parameter \( p \) is already known from the definition of the problem.

Blurred images are the results of low-pass filtering followed by a noise addition. We consider Gaussian blur with known radius \( \sigma \) and a noise with Gaussian distribution. There is no frequency cut off, and parameter \( p \) depends on image deburring method. For the unsharp mask, we use \( p = k\sigma \), where \( 2.5 \leq k \leq 3 \).

We have performed frequency analysis of different image enhancement algorithms to confirm the proposition that parameter \( p \) can be estimated from image degradation method. For a pair of reference image \( \nu \) and restored image \( u \) we calculate the cumulative spectrum error function \( A(w) \) (CSEF):

\[
A(w) = \frac{2\pi}{\int_0^{2\pi} |f(w\cos\theta, w\sin\theta)|^2 d\theta},
\]

where \( f(w_1, w_2) \) is linearly interpolated discrete Fourier transform of the error image \( f = u - \nu \).

The analysis consists in calculating average CSEFs \( A(w) \) for reference images from the set of standard images (baboon, cameraman, house, goldhill, lena, peppers) for popular methods of image resampling, deringing and deblurring. The results of this analysis for \( p = 2 \) are shown in Fig. 3. It can be seen that most of the image enhancement methods produce error in high-frequency domain and the change of the curve shape happens in the expected point \( w = \frac{1}{2p} = \frac{1}{4} \).

2. BASIC EDGES

Blur and ringing effect appears near sharp edges. But an arbitrary sharp edge cannot be used for image quality analysis. Some edges can disappear or can be displaced after image corruption. If these edges are used to analyze blur and ringing effect, the results will be incorrect.

There are two effects observed in images with corrupted high frequency information:

1. Masking effect. If an edge with low gradient value is located near an edge with high gradient value, it will disappear after image degradation.