Regularization parameter choice for total variation based image deringing algorithm

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Abstract

The problem of finding regularization parameter for image deringing algorithm is considered. Different images from the ringing database with modelled ringing effect were processed by total variation based ringing suppression algorithm. Reference images were used to find deringing parameter values for every image. The functional dependence between deringing parameters and ringing level was found that can be used to perform no-reference image ringing suppression.

Keywords: *ringing effect, deringing, total variation, regularization parameter.*

1. INTRODUCTION

Development of image enhancement methods is one of the most important image processing tasks. Ringing effect (Gibbs phenomenon) appears in images as oscillations near sharp edges. It is a result of a cut-off of high-frequency information. Mathematical aspects of ringing effect are discussed in [1], [2].

Ringing can appear as a result of image compression, image upsampling and other applications. An example of frequency cut-off ringing effect can be seen in Fig.1.

Figure 1: An image with ringing effect.

One of the main problems of image deringing is to detect the presence of ringing effect. The most of existing ringing estimation algorithms are designed for specific problems like image deringing after JPEG or JPEG-2000 compression [3], [4], [5] and image deringing after a certain type of image processing [6].

Several approaches for ringing level estimation in general case were developed but most of them have limited use. In [7], the ringing metrics is defined as maximum of the differences between pixel values of the reference image and the processed image in the edge neighborhood, but the size of this neighborhood is fixed a priori. In [8], the presence of ringing effect is detected by comparing the directions of image gradients at different scales. The work [9] does not introduce a ringing estimation method, but it presents an algorithm to find regions where the ringing effect is the most visible. It is based on luminance masking and texture masking as typical for the human visual system.

The paper [10] introduced a general case no-reference ringing estimation method using the ratio between weighted total variation values of edge profiles after Gaussian blur with different parameters.

Another problem is to estimate the necessary ringing suppression level. In our work, we consider the problem of parameter estimation for an efficient deringing algorithm described in [10]. This algorithm is based on projection of image onto the set of images with bounded total variation (TV). The TV was first used in image enhancement by Rudin, Osher and Fatemi [11] for image denoising. General relations between TV and ringing effect can be found in [12].

The method to choose the deringing parameter for TV based algorithm for the problem of image deringing after resampling is proposed in [13]. For the general case, the paper [10] suggests to choose the deringing parameter a posteriori by iteratively varying the deringing parameter until the estimated ringing level of the result image is equal to the target ringing level. This approach requires performing a number of deringing algorithm applications with different deringing parameters.

In this paper, we propose a method to choose the deringing parameter for the TV based deringing algorithm a priori using one application of the deringing algorithm with fixed regularization parameter.

2. RINGING ESTIMATION ALGORITHM

We use the ringing estimation algorithm introduced in [10]. The algorithm consists of the following steps:

1. Finding edges the most suitable for ringing analysis.
2. Performing edge width estimation and the extraction of edge profiles from the found edges.
3. Calculating the ringing estimation value for every edge profile.
4. Output the image ringing level as the median value of ringing estimation values for edge profiles.

The ringing estimation value for a one-dimensional edge profile $f(x)$ centered in $x=0$ is defined as:

$$R_E = \frac{TV(f, kd, w_{\alpha d})}{TV(f, d, w_{\alpha d})}, \qquad (1)$$

where

$$TV(f,\sigma,w) = WTV(f * G_\sigma, w),$$

$$WTV(g,w) = \int_{-\infty}^{+\infty} |g'(x)|\, w(x) dx .$$

Here $f * G_\sigma$ is a convolution of $f(x)$ with Gaussian filter with the radius σ. The weight function $w_{\alpha d}$ is equal to:

$$w_{\alpha d} = e^{-\frac{x^2}{2(d)^2}} .$$

The parameter α controls the number of considered ringing oscillations. We use the value $\alpha = 3$.

The value d is the estimated edge width [10].

The parameter k depends on α and the noise level. We use the value $k = 0.25$ that was obtained experimentally.

3. RINGING SUPPRESSION ALGORITHM

We use a projection method of an image into the set of images with bounded total variation to perform ringing suppression [10]:

$$z_q = \arg \min_{\|z\|_V \le q\|z_0\|_V} \|z - z_0\|_2^2, \qquad (2)$$

where z_0 is the input image with ringing effect, $\|z\|_V$ is the total variation functional:

$$\|z\|_V = \sum_{i,j} |z_{i+1,j} - z_{i,j}| + \sum_{i,j} |z_{i,j+1} - z_{i,j}|,$$

and q is the ringing suppression level — the ratio between the total variation of the result image and the source image.

Subgradient method and projection gradient method are used to minimize the target functional (2) [13].

4. FINDING OPTIMAL DERINGING PARAMETERS FOR IMAGES FROM THE RINGING DATABASE

We have developed the special ringing database containing 35 reference images with ringing effect modeled by different methods [14]. The reference images are real images that contain nature and architecture objects. Ringing effect is modeled by interpolation, sharpening and low-pass filtering and compression algorithms.

For every image in the database we perform a series of applications of deringing algorithm (2) with q in the range of [0, 1] and calculate ringing level values R_E.

Experiments has shown that the functional dependence

$$f(q) = R_E(z_q), \qquad (3)$$

is close to linear function in [0.5, 1] range. Examples of $f(q)$ functions for different input images are shown in Fig. 2.

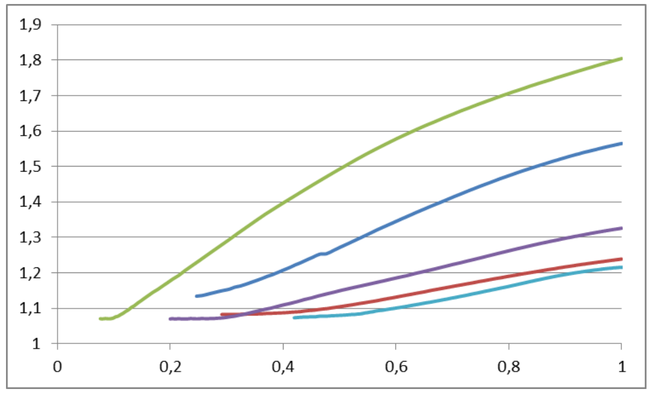


Figure 2: Examples of $f(q)$ functions (3) for different input images.

We estimate the function $f(q)$ with a linear function

$$g(q) = 2(f(0.5)(1-q) + f(1)(q-0.5))$$

and calculate the maximum error

$$\max |f(q) - g(q)|, \quad q \in [0.5, 1].$$

The average of maximum errors was found as 0.02 while the standard deviation was 0.015 on the set of 900 images from the database [14] that do need deringing.

It makes possible to use the estimation $g(q)$ instead of $f(q)$ to choose the deringing parameter. The image deringing algorithm is applied twice: first with $q = 0.5$, then with interpolated q. To achieve more accurate result, the secant method can be used.

5. RESULTS

The proposed method of finding deringing parameter is demonstrated in Fig. **Figure 3**3 for target $R_E = 1.2$.

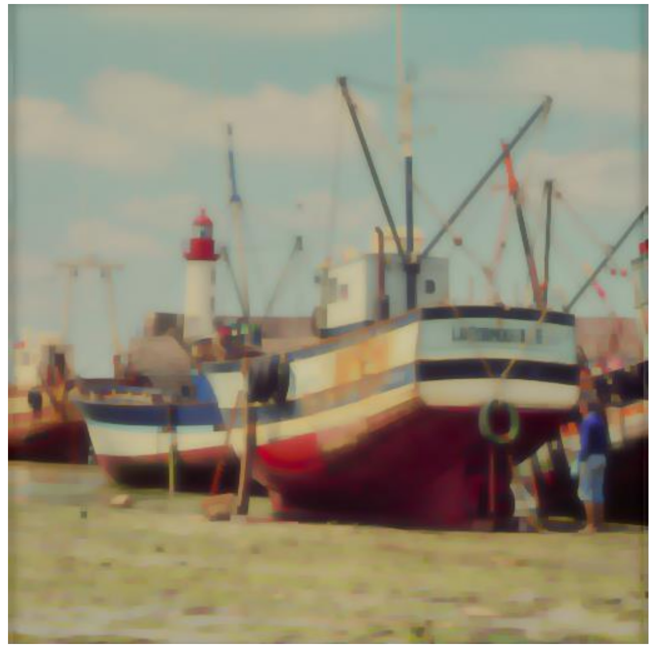
The ringing value for the input image is 1.388, the ringing value after deringing with $q = 0.5$ is 1.124. To achieve ringing level equal to 1.2, we choose $q = 0.654$. The ringing level of the obtained image is 1.204, the MSE and SSIM values are significantly better than for the input image.

a) The reference image from the database.

$R_E = 1.286$

b) The image with modeled ringing effect.

$R_E = 1.388$, $MSE = 196$, $SSIM = 0.955$



c) Application of the deringing algorithm with $q = 0.5$.

$R_E = 1.124$, $MSE = 567$, $SSIM = 0.954$

d) Application of the deringing algorithm with $q = 0.654$.

$R_E = 1.204$, $MSE = 65$, $SSIM = 0.984$.

Figure 3: Application of the proposed method for image deringing.

4 images: reference, with ringing, after preliminary ringing reduction, final ringing reduction with target ringing level.

6. CONCLUSION

The experimental analysis of finding the ringing suppression parameter for no-reference ringing effect reduction has been performed. Nearly linear dependence of ringing level on the deringing parameter has been shown. A method to choose the deringing parameter according to the target ringing level has been proposed.

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