Image warping as an image enhancement post-processing tool

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Abstract

A method to improve the results of image enhancement is proposed. The method is based on pixel grid warping, the main idea is moving pixels in the direction of the nearest image edges. Warping allows to make edges sharper while keeping textured areas almost intact. Experimental applications of the proposed method for image enhancement algorithms show the improvement of image quality.

1 Introduction

There are some fairly powerful techniques for image deblurring [1], [2], [3]. The typical problem of image deblurring methods is finding optimal parameters for a compromise between smooth result with blurry edges and sharp result with artifacts like ringing or noise amplification. In this work we present a new post-processing algorithm for image deblurring with enhancement of edge sharpness.

We localize the area of interest to the neighborhood of the edges. The idea is to transform the neighborhood of the blurred edge so that the neighboring pixels move closer to the edge, and then resample the image from the warped grid to the original uniform grid.

The warping approach for image enhancement was introduced in [4]. The warping of the grid in this work is performed according to the solution of a differential equation derived from the warping process constraints. The solution of the equation is used to move the edge neighborhood closer to the edge, and the areas between edges are stretched. The method has several parameters, and the choice of optimal values for the best result is not easy. Due to the global nature of the method the resulting shapes of the edges are often distorted. In [5] the warping map is computed directly using the values of left and right derivatives. In both methods [4] and [5] the pixel shifts are proportional to the gradient values. It results in oversharpening of already sharp and high contrast edges and insufficient sharpening of blurry and low contrast edges. Both methods also introduce small local changes in the direction of edges and produce aliasing effect due to calculation of horizontal and vertical warping components separately.

2 Warping technique

In this section we describe the idea of a single edge enhancement using a pixel grid transformation. The profile of a blurred edge is more gradual compared to a sharp edge profile. So in order to make the edge sharper its transient width should be decreased (see Fig. 1).

2.1 Warping of a one-dimensional signal

The idea of one-dimensional edge sharpening is based on the assumption that the edge can be approximated by a step-edge function $H(x)$ smoothed with a Gaussian filter G_σ with a standard deviation σ [6]:

$$E_\sigma(x) = [H * G_\sigma](x), \quad \text{where } H(x) = \begin{cases} 1, & x \geq 0, \\ 0, & x < 0, \end{cases} \tag{1}$$

One-dimensional grid warping (2) is performed according to the following equation:

$$\tilde{x} - x = AG'_\sigma(\tilde{x}), \tag{2}$$

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a. Proposed approach: pixels are shifted   b. Typical image enhancement approach
pixel values are modified

Figure 1: The idea of edge sharpening

where x is the old position of pixel $E_\sigma(x)$, $\tilde{x}$ is the new position, $A > 0$ controls the strength of grid warping. This model ensures that the shape of the edge is not distorted and the grid transformation is smooth.

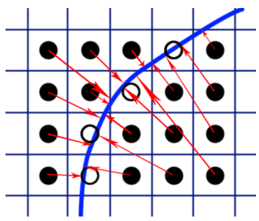
To avoid a discontinuity of the solution of the warp equation (2), the strength parameter A should be such that $A < \frac{1}{\max\limits_{x\in\Re} G''_\sigma(x)}$. We use $A = 0.99 \cdot \frac{1}{\max\limits_{x\in\Re} G''_\sigma(x)}$ in order to get a strong sharpening effect.

2.2 Image warping

The idea of the proposed algorithm for one-dimensional signal warping needs to be adopted for application for two-dimensional images. Two variants of the image warping are suggested.

2.2.1 Two-dimensional extension

In the two-dimensional case, the pixels are surrounded by a number of edges. Choosing the right direction of pixel warping requires additional analysis. The simplest algorithm is finding the nearest edge for every pixel and apply the one-dimensional algorithm using that edge. It consists of the following steps:
1. Estimate the blur level (the average standard deviation of Gaussian filter) for the edges.
2. For all pixels in the neighborhood of the edge compute the distance d to the nearest edge point.
3. Compute pixels' displacements (see Fig. 2) using equation (2) with $x \equiv d$.
4. Interpolate the image from the warped grid to the old uniform grid.



The thick line represents the exact edge location, white circles represent edge pixels,
black circles represent pixels from the edge neighborhood

Figure 2: Displacements for two-dimensional grid warping

The edge map at the input of the algorithm has a great influence on the result of grid warping as only detected edges will be sharpened. In our work we use the result of Canny edge detection [7] as the input of the algorithm. The result of image warping is highly dependent on the input edges. The parameters of the Canny method (σ and high threshold T_{high}) are chosen individually for each image.

2.2.2 Poisson warping

To take into account several edges simultaneously to avoid possible discontinuities between edges, we propose a 2D image warping algorithm which computes the displacement field directly as a 2D vector field $\vec{d}(x, y)$ with some obvious constraints (see Fig. 2).

1) The shapes of the edges cannot be warped, so $\vec{d}(x_e, y_e) = 0$ for each edge point (x_e, y_e).

2) Also, there cannot be any turbulence: rot $\vec{d} = 0$. Since rot$\nabla u \equiv 0$, the displacement field is assumed to be gradient of some scalar function $u(x, y)$: $\vec{d}(x, y) = \nabla u(x, y)$.

3) The edge neighborhood points situated farther from the edge cannot move closer to the edge than the neighborhood points situated nearer to the edge: div $\vec{d} \geq -1$.

Since div$\nabla \equiv \Delta$, where Δ is a Laplacian, the warping problem can be posed as a Dirichlet problem for the Poisson equation in the area of the image:

$$\begin{cases} \Delta u & = p(x,y) - 1, \\ u(x,y) & = 0 \text{ at image borders} \end{cases}, \quad \text{where } p(x_0,y_0) = \frac{\sum\limits_{(x,y)\in E(x_0,y_0)} p(x_n) G_\sigma(x_t) |\vec{g}(x,y)|}{\sum\limits_{(x,y)\in E(x_0,y_0)} |\vec{g}(x,y)|} \tag{3}$$

The second constraint here is the boundary condition: the displacements at image borders should be equal to zero; $p(x,y)$ is the proximity function that describes the distance between adjacent pixels after image warping; $E(x_0,y_0)$ is the set of edge points in the neighborhood of (x_0,y_0); the values x_n and x_t are projections of the vector $(x_0 - x, y_0 - y)$ on the edge gradient vector $\vec{g}(x,y)$ and on the tangent to the edge respectively; $p(x_n) = 1 - AG''_\sigma(x)$; $G_\sigma(x_t)$ is the weighting function with standard deviation equal to the edge's blur σ.

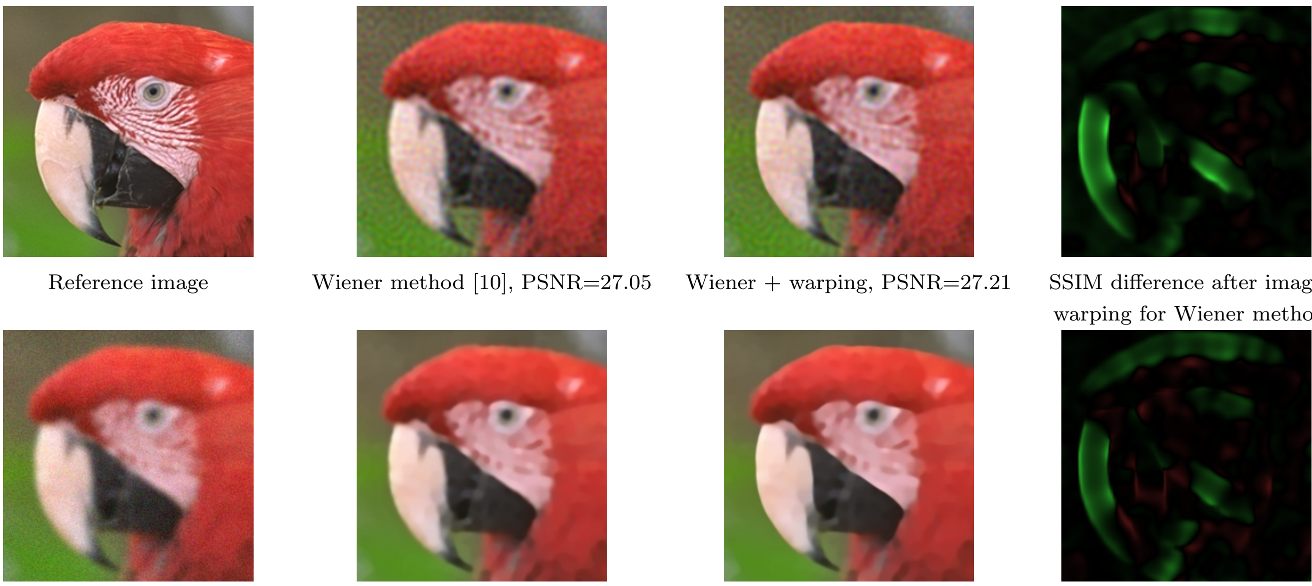
We solve the equation (3) by Gauss-Zeidel method.

3 Results and experiments

We applied the image warping as a post-processing algorithm for image deblurring and TV image enhancement algorithms. The proposed method was tested on 29 images from LIVE database [8]. The images were blurred with Gaussian kernel with random radius in the range $[1,6]$, then Gaussian white noise with random standard deviation in the range $[0,10]$ was added. After that we applied existing deblurring algorithms followed by image warping using known blur level. Table 1 represents the result. Preliminary experiments with automatic estimation of the unknown edge width [9] also show the enhancement of deblurring methods.

The Poisson warping shows a bit better results than 2D extension of 1D warping. It produces smoother edges but is about 10 times more computationally complex.

The example of the proposed Poisson warping is shown on Fig. 3. It can be seen that the edges become better and the overall quality is improved. Nevertheless, small SSIM degradation regions exist. They correspond to the initially blurred regions of the image. Of course, an unwanted sharpening effect for the blurred areas of the original image can appear but it is a rare case.



Reference image | Wiener method [10], PSNR=27.05 | Wiener + warping, PSNR=27.21 | SSIM difference after image warping for Wiener method

Degraded image, PSNR=25.99 | TVMM [2], PSNR=28.66 | TVMM + warping, PSNR=28.72 | SSIM difference after image

Figure 3: Poisson warping algorithm example. Green areas show improvement of SSIM, red — degradation.

In [12] was shown that the proposed warping approach is a good post-processing tool in image ringing suppression and resampling.

Method	No warping	2D ext warping	Poisson warping
Blurred and noisy images	22.84	23.29	23.25
Unsharp masking	23.00	23.54	23.36
TV regularization	23.30	23.35	23.40
Low-frequency TV reg. [11]	23.08	23.15	23.18
TVMM [2]	23.31	23.33	23.48
Lucy-Richardson [10]	23.83	23.94	23.99
Wiener [10]	24.00	24.08	24.17
MatLab blind deconvolution	23.79	23.93	23.96
Average	23.39	23.58	23.60

Table 1: Average PSNR values for images from LIVE database with added blur and noise

4 Conclusion

The proposed image warping method has a great potential to improve the results of existing image enhancement algorithms. It is especially effective for total variation based image enhancement algorithms because image warping does not significantly change total variation value. It can also be used as a standalone image sharpening algorithm. It is a good choice in the presence of strong noise and complex and non-uniform blur kernel.

In comparison to existing sharpening approaches, the proposed method introduces no artifacts like ringing effect nor noise amplification, the resulting images look natural and do not inevitably become piecewise constant.

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