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ИСОИ IPSI

Image Processing Systems Institute of RAS

ПОСТРОЕНИЕ ДВУХЭТАПНОГО ЛИНЕЙНО-НЕЛИНЕЙНОГО ФИЛЬТРА ДЛЯ ВОССТАНОВЛЕНИЯ И КОРРЕКЦИИ ИЗОБРАЖЕНИЙ

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Plan of the Report

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1. Motivation

Increase in the number of mobile devices and systems with function image capture

Blur may occur due to small depth of the lens sharpness, or relative movement of the device and the object being recorded at take up photography without using a tripod

Problem Analysis, choice of the Filter Class

Options: FIR- or IIR-filter?

IIR-filter: a higher quality of recovery is achievable.

Shortcomings:

1. Not always can be realized for an arbitrary form of the support window.

2. Problem of filter stability.

FIR-filter: The quality of the recovery is usually slightly lower than the IIR filter.

Advantages:

1. Easy implementation at arbitrary shape of the support window.

2 Always stable.

Important requirements to filters & questions

1 Simplicity of the filter parameters estimation.

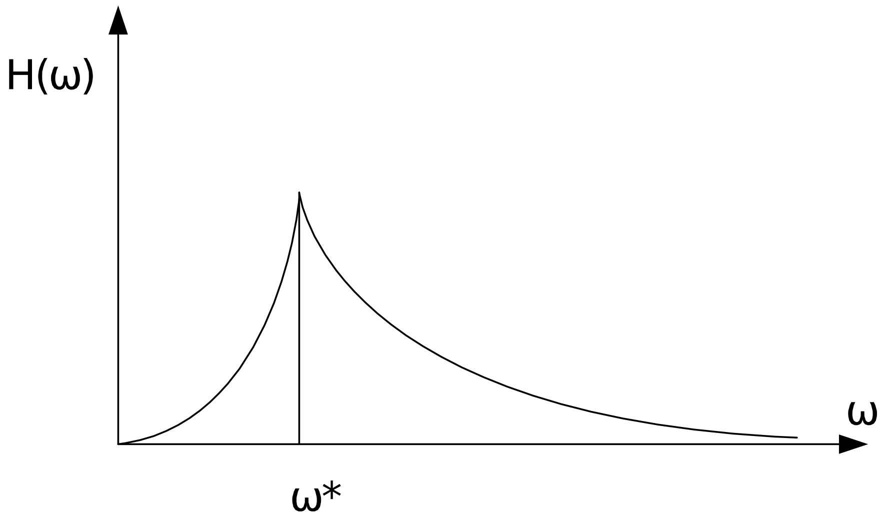
2. Ability of the filter parameters estimation in the absence of test images (including on visual perception).

- **Training on test samples using a neural network?**
- **Usually there are no test images, if any - long learning time.**
- **Wiener 's filter?**
- **Usually there is no information on frequency characteristics of noise and blur.**
- **There are many other approaches and methods with these disadvantages**

Proposed filter frequency response

We assume that distortions have (central) radial symmetry

The two-dimensional frequency response is a result of rotating of the one-dimensional frequency response around the center of the support window



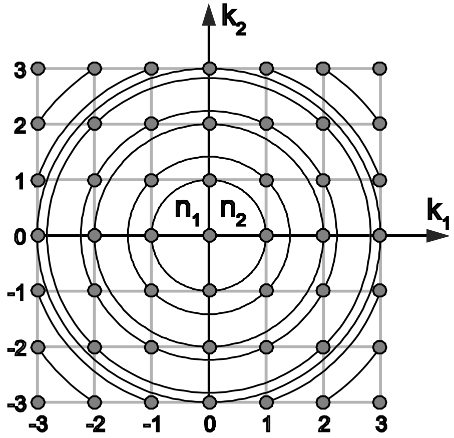
$$S(\omega) = \begin{cases} a\omega^2, & \text{if } 0 \le \omega \le \omega_1, \\ e^{-c\omega}, & \text{if } \omega > \omega_1, \end{cases} \quad (1)$$

$$S(\omega_1) = a\omega_1^2 = e^{-c\omega_1}. \quad (2)$$

Impulse response of the filter

Inverse Fourier transform of a one-dimensional frequency response:

$$h(r)=\frac{e^{-c\omega_1}}{\pi}\left\{\frac{\sin(\omega_1 r)}{r}+\frac{2\cos(\omega_1 r)}{\omega_1 r^2}-\frac{2\sin(\omega_1 r)}{\omega_1^2 r^3}+\frac{\sin(\omega_1 r)-\sin(\omega_1 r)}{r}+\frac{c\cos(\omega_1 r)-r\sin(\omega_1 r)}{c^2+r^2}\right\}, \qquad (1)$$

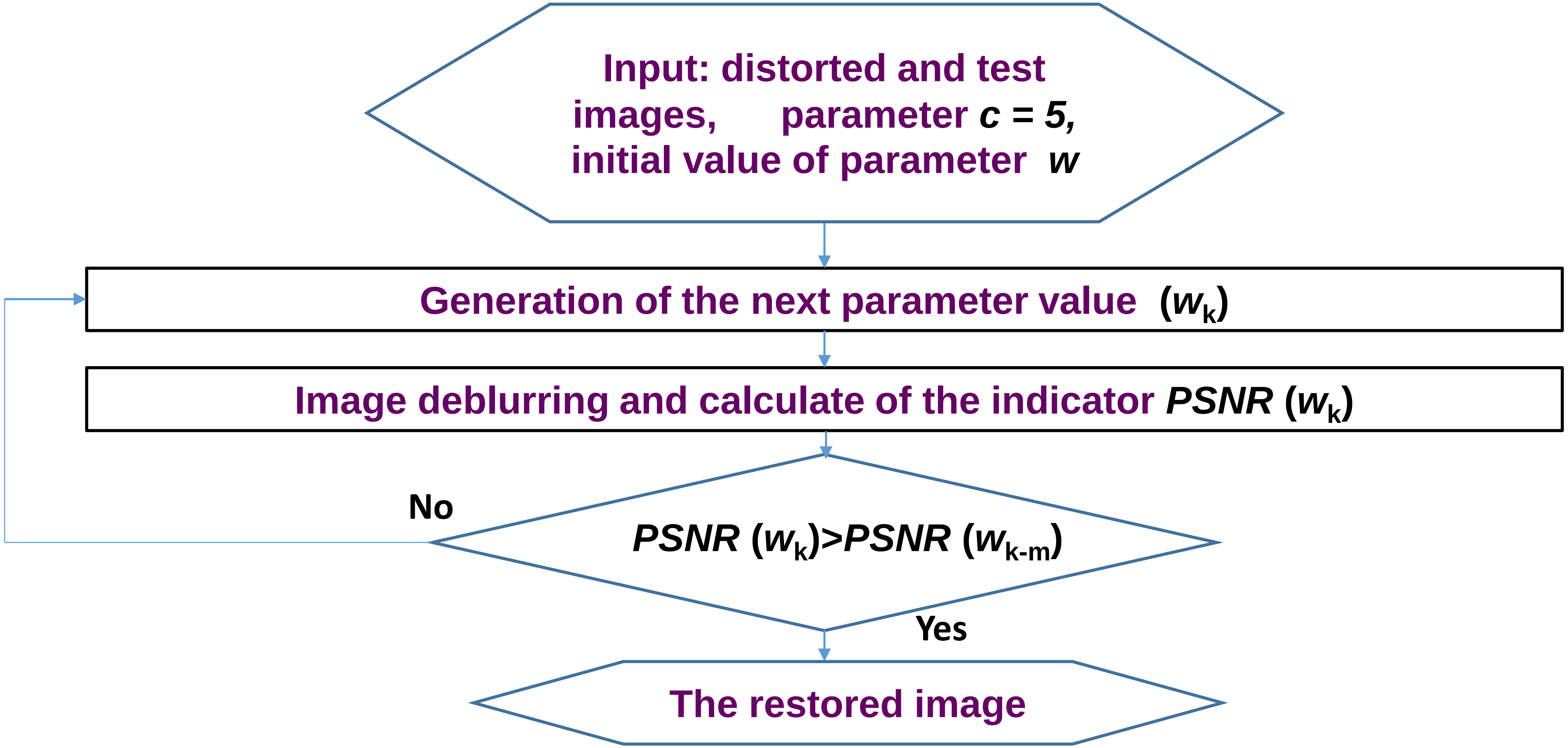


$$r(k_1,k_2)=\sqrt{k_1^2+k_2^2}. \qquad (2)$$

$$h(0)=\lim_{r\to 0}h(r)=\frac{\omega_1 c+3}{3c\pi}e^{-c\omega_1}, \qquad (3)$$

$$y(n_1,n_2)=\sum_{k_1}\sum_{k_2}h[r(k_1,k_2)]\,x(n_1-k_1,n_2-k_2). \qquad (4)$$

Filter optimization algorithm using a test image



Key considerations for blind deblurring

- **Let's emphasize: when images are registered by the user of the mobile device, it is not possible to optimize the filter, since there is always no test image.**
- **Optimization of the filter using the test image can be performed by the designer when constructing the device with the new optics.**

- **Problem: we can only compare distorted and corrected images, with PSNR decreasing as image quality improves**
- **We will use the following property: as the blur decreases, the variance of the brightness distribution function on the image increases**

Linear filter optimization algorithm for blind deblurring

1. We set the initial value of the parameter $\hat{\omega}_k$

2. Image Deblurring is performed and calculate the indicator $PSNR(\hat{\omega}_k))$

   and the standard deviation $SD(\hat{\omega}_k)$

3. The following conditions were checked

$$PSNR(\hat{\omega}_k) < PSNR(\hat{\omega}_{k-m}),$$
$$SD(\hat{\omega}_k) > SD(\hat{\omega}_{k-m}).$$

The process stopped if $PSNR(\hat{\omega}_k) > PSNR_{th}$

where $PSNR_{th}$ is a threshold value

Line filter recovery results

Parameters of a linear filter: $\hat{c} = 5, \quad \hat{\omega} = 0,855.$

Initial «monarch» image

after blurring

deblurring with linear filter

The achieved results: PSNR = 27.061

Key questions and the idea of non-linear filtering

Problems:

- Achievable quality by line filter recovery is limited.
- To improve quality, it is necessary to increase the contribution of high frequencies, but this will lead to increased noise.

How to increase sharpness but avoid increasing noise in the image?

The idea: Frequency properties of the noises and distortions are similar, therefore we want to separate them in space.

Technology Stages

→ **Linear Filter** → **Nonlinear Filter** →

Simplified representation of a nonlinear filter

$$y(n_1,n_2)=x(n_1,n_2)+F_a(t) \quad (1)$$

where

$F_a(t)$ is a non-linear function (2)

$t=T_a(\mathbf{x}_D)$ is some transformation of the set of samples into a scalar (3)

$\mathbf{x}_D$ is the set of samples in the area D

D is the support window

Transformation of the set of samples into a scalar

$$t = T_a(\mathbf{x}_D) = \sum_{\substack{k_1,k_2 \in D \\ k_1,k_2 \neq 0}} h(k_1,k_2)\,\Delta x(n_1+k_1, n_2+k_2) \quad (1)$$

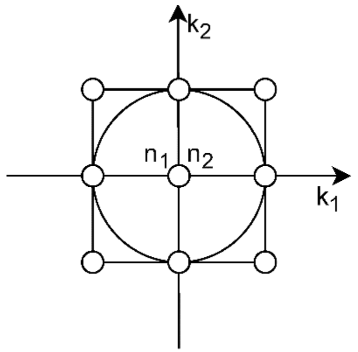
where $h(k_1,k_2)$ is the given weight matrix

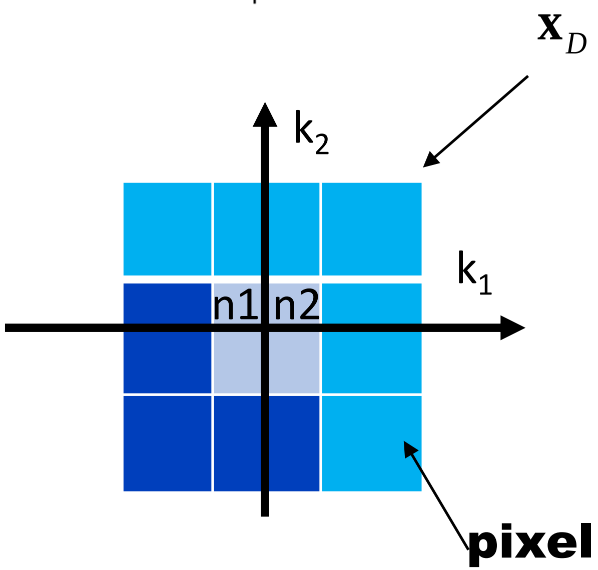
$$h_{k_1,k_2} = h_0 / \sqrt{k_1^2 + k_2^2} \quad (2)$$

where h_0 is the normalizing coefficient:

$$h_0 = (m-1) / \sum_{\substack{\forall k_1,k_2 \in D, \\ k_1,k_2 \neq 0}} \left(k_1^2 + k_2^2\right)^{-1/2} \quad (3)$$

m is number of points in the support window





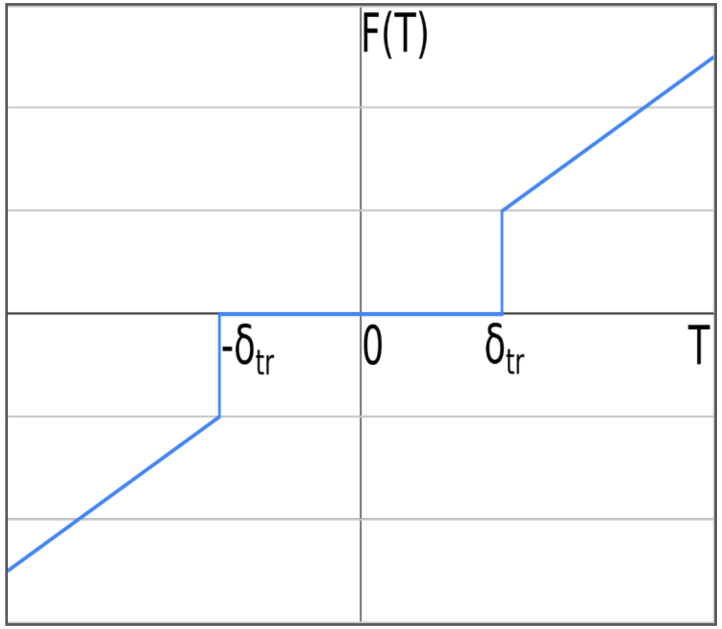
Non-linear function of the filter

$$y(n_1,n_2)=x(n_1,n_2)+F_a(t)$$

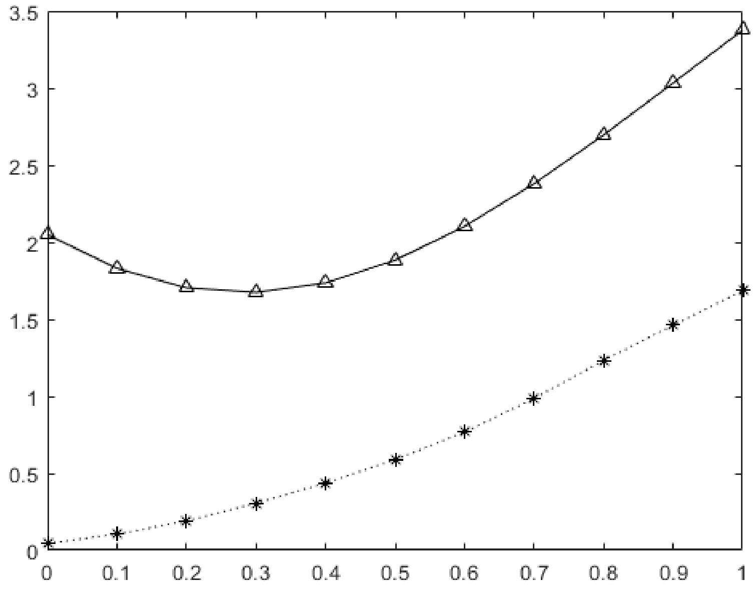
$$F(t)=0 \quad at \quad |t|\le\delta_{tr}$$

$$F(t)=k\cdot t \quad at \quad |t|>\delta_{tr}$$

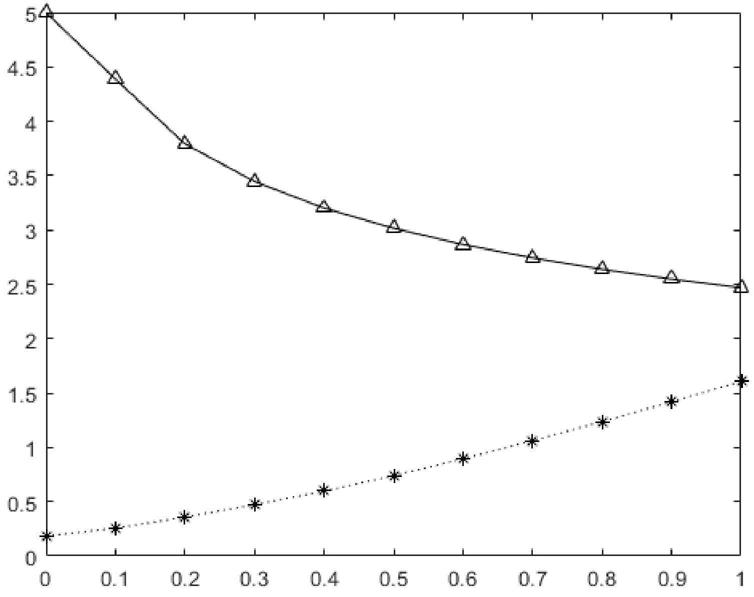
- **It can be seen that in areas with low gradient of luminance function, the image is not subject to changes.**
- **So in these areas noise is not amplified.**



Dependence of the rate of artifacts in % (*) и PSNR difference between initial and processed images (Δ) on the parameter *k*



Using a test image



Blind deblurring

Filter parameter estimation technology

Test Image

- **Step 1. Optimization of parameter *k* at the given $\delta = 0$ using a measure of proximity to the test image - *PSNR*.**
- **Step 2. Optimization of parameter δ at obtained *k***

Blind deblurring

- **Step 1. The definition of parameter *k* at the given $\delta = 0$ so as to provide a given value of the measure of difference from the original image by the indicator *PSNR*.**
- **Step 2. Determination of parameter δ when *k* is obtained so as to provide a predetermined value of the difference measure from the same image by the indicator *PSNR*.**

Image correction using a test sample image

Results of the correction using an initial test image «monarch»

deblurring with linear filter

$PSNR = 27.061$

Nonlinear deblurring with

$k_a = 0,28 \quad \delta_{tr,a} = 0,0$

$PSNR = 27.681$

Nonlinear deblurring with

$k_a = 0,28 \quad \delta_{tr,a} = 0,035$

$PSNR = 27.698$

It was 0.637 more than that achieved using only linear filtering

Image correction by blind deblurring

Deblurring results of the image “bird” by blind correction method

initial distorted diffraction image

deblurring with linear filter

Nonlinear deblurring with

$\hat{k} = 0.5 \quad \delta_{tr,a} = 0,0$

$PSNR(X^*, \hat{X}) \cong 30,0$

Nonlinear deblurring with

$\hat{k} = 0.5 \quad \delta_{tr,a} = 0,08$

$PSNR(X^*, \hat{X}) \cong 31,0$

Unfortunately, we can estimate quality visually only

Example of an image processing obtained by a diffraction lens

In this case we had no good original of a test image

Therefore we can estimate the quality of processing only by subjective perception

Conclusion

- Non-linear image correction after the linear filtration allowed us to improve the detailing on image.
- An important advantage of the proposed technology is the small number of parameters and simplicity of their training.
- The use of non-linear functions of a more complex type we consider to be a direction for further research.
- The proposed technology was aimed at improving the quality of images in mobile devices. The ability to obtain more details in low-resolution images at relatively low computational costs opens up the prospects for the use of objectives based on the diffraction optic elements in mobile devices

Thank you for your attention