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SEGMENTATION OF PARTIALLY-BLURRED IMAGES USING WAVELET TRANSFORM

In the research a method for segmentation of partially-blurred images using the wavelet transformation, particularly coiflet of the order *L=3* is presented. The entropy is used as a segmentation criterion based on wallet transformation. *K*-means method is used for image segmentation. Developed method was tested and has shown good results of his work; it correctly performs more than 82 % of pixels of image, and in many individual cases, more than 90 %.

Key words: image processing, partially-blurred images, wavelet transformation, entropy, *k*-means clustering.

Розроблено метод сегментування частково спотворених зображень із використанням вейвлет-перетворення, зокрема, койфлета порядку *L=3*, і ентропії як критерію сегментування. Застосовано метод *k*-середніх для сегментації зображення на основі розробленого критерію. Здійснено тестування методу, результати якого показали хороші показники сегментування, а саме: метод дає змогу досягти правильної сегментації більше ніж 82 % пікселів, а в багатьох окремих випадках більше ніж 90 %.

Ключові слова: обробка зображень, частково спотворені зображення, вейвлет-перетворення, ентропія, метод *k*-середніх.

Introduction

There is often happens in practice, when the image acquisition process is accompanied by the presence of any type of blurriness, such as Gaussian blur, motion blur, loss of contrast, noise effect and so on. The vast majority of modern methods of blur eliminating require that all image's pixels underwent identical type and degree of blurriness. However, this is not always true; especially for Gaussian blur and motion blur that can occur in a certain part of the image only. Examples of such partial blurring are shown at the Fig. 1.

a b

Fig. 1. Examples of partial blurred images: a – with Gaussian blur; b – with motion blur

The blurring process can be described by the linear model (1) [0, 0]:

$$G = F * H + \eta, \tag{1}$$

G – blurred image; F – original un-blurred image; H – kernel of blurring; η – additive noise; * – convolution operation.

In this research the noise component is not included, because we can usually assume that whole image underwent the same noise effect, as well as nowadays there are developed many techniques, which allow eliminating its impact. As it is mentioned above, different parts of an image may be subject to various distortions, namely there are some blurring functions $H_1, \ldots, H_N$, which were applied to different areas of the image that do not intersect. That is, partly blurred image G can be represented as N regions (segments, clusters) $G_1, \ldots, G_N$, such as $\bigcup_{i=1}^{N} G_i = G$ and $G_i \cap G_j = \varnothing \quad \forall\, i = 1..N,\ j = 1..N,\ i \neq j$ and $G_i = F_i * H_i + \eta$, where F_i – un-blurred part of the image, corresponding to G_i.

Thus, the essence of the problem is the following: a) establishing the criteria, which for each point *(x, y)* of the input image G would determine the degree of blur at this point; b) image segmentation, based on this criterion.

Analysis of recent research and publications

In [0] the segmentation method of the partially-blurred images with the four criteria and their combination is determined using the Bayesian classifier. The authors used the following segmentation criteria: a) Local Power Spectrum Slope, which is based on the application of Fourier window transform; b) a criterion based on the evaluation of the image's gradient histogram; c) colour saturation criteria in different parts of the image, d) Local Autocorrelation Congruency, which is used to classify the type of blurriness, Gaussian blur or motion blur.

In the research [0] the use of the images singular decomposition is proposed. Namely, for each window of a certain size its singular decomposition is calculated and the ratio of sums of the left singular vectors' elements of the window and the whole image is used as a segmentation criterion. For segmentation, using criteria developed, the approach based on global threshold value, which was determined experimentally in advance, is applied.

The method of determining the degree of the blurring of whole image using wavelet transformation is described in [0]. The nature of the method lies in building the edge map, using the wavelet transformation based on the Haar wavelet with further identification and assessment of four different structures of the image edges (Dirac, Astep, Gstep, Roof) and building criteria on them.

Several criteria of image blurriness determination based on different statistical characteristics are considered in [0]. Namely: a) Structural Similarity Index, which is based on a comparison of the structures of input image with its transformed version that is obtained after subtracting brightness and variance normalization; b) the Average Edge Width, which can be calculated after applying the Sobel operator; c) the Cumulative Probability of Blur Detection, the essence of which lies in function, by means of which, considering the width of the borders, contrast and some other parameters, probability of blurring is calculated.

Aim of work

Research and construction the criteria of determination the blur degree of different parts of the image using wavelet transformation and development of its segmentation method.

Work description

It is known that the process of blurring has low-pass-filtering characteristics, so some high frequency components are lost. This property has particularly strong influence on the edges of the image objects. During blurring they become less clear, that is brightness difference is reduced between edge pixels and neighbouring pixels.

Wavelet transformation is widely used in image processing, including the fact that the local maximum of wavelet transformation allows to detect irregular structure, in particular, such as edges of objects [0].

The result of the image wavelet transformation is pyramid-like hierarchical structure, on each level (scale) of which four components are available: HL_i – horizontal component of transformation,

LH_i – vertical component, HH_i – diagonal component, LL_i – reduced twice copy of LL_{i-1} (LL_0 – an input image), i – the level number. Each component is a matrix (image) with the size twice less than the corresponding element in the previous scale [0, 0].

Edge map, which is formed being based on wavelet transformation at scale i is called [0]:

$$Emap_i(x, y) = \sqrt{LH_i(x, y)^2 + HL_i(x, y)^2 + HH_i(x, y)^2} . \quad (2)$$

By criterion constructing in this research only scale 1 of wavelet transformation is used. Edge maps for two partially-blurred images (see Fig. 2a, and Fig. 2b) are presented in Fig. 2c and Fig. 2d.

These images clearly show that their sharp parts contain much larger number of bright pixels in the edge maps than not sharp one, because of the properties of wavelet transformations.

However, while using only brightness value of a pixel, it is impossible to establish the degree of its blur clearly, as the sharp area also contains the pixels with low brightness (namely, where there are no boundaries). It is therefore necessary to consider some its surroundings, such as a square window sized $N \times N$, where N – is odd, with the centre in the tested pixel (in the coordinates of this pixel ($\lfloor N/2 \rfloor+1, \lfloor N/2 \rfloor+1$)). Besides, the blur value is the result of the some function of this surrounding.

In this research we propose to use entropy as a function of the elements of its surroundings, because its value will be greater in sharp areas and smaller at less sharp ones due to the large number of bright pixels with different degrees of brightness in sharp areas and smaller number of less sharp ones.

The result of applying entropy as a criterion based on wavelet transformation in the window sized 25×25 (window size is determined experimentally) is presented in Fig. 2e and Fig. 2f. It is to be noted that for the pixels that are at a less distance than $\lfloor N/2 \rfloor$ from the image edge, we cannot select the screen of the size we need. Therefore, in this research for these pixels entropy is calculated at the maximum available window, which size is smaller than it is required. In this regard, some blur values may be not fully correct in "by-edge" areas, but, as the experiments results show, they are insignificant.

As the method of segmentation (clustering) in the research the method of k-means with a given number of clusters in advance is used. So, an example of segmentation result by 2 clusters is shown in Fig. 2g and Fig. 2h.

As a summary, it is to be stated that the proposed segmentation method using wavelet transformation can be represented by the following sequence of actions:

1. For the input image G wavelet transformation is applied to obtain the first magnitude: HL_1, LH_1, HH_1 and LL_1. As the result of the research it is found that the best segmentation results are achieved using *coiflets*, namely the *coiflet* of the order $L = 3$ [0].

2. *Emap* (edge map) is formed according to (2).

3. For each pixel of *Emap* is calculated entropy in the window $N \times N$, resulting on receiving E – matrix of the criteria values for each pixel of *Emap*.

4. The size of E increases twice (e.g. using Bicubic interpolation), while receiving E', as it should be taken in line with each pixel of input image a certain degree of blur, and G is twice larger than E.

5. Image segmentation is done based on the obtained criterion E'. As the segmentation method using k-means [0] with known number of clusters in advance is proposed.

To test the method a database with 84 clear images and developed program is used. The program, developed in the MATLAB environment and allows to create partially-blurred version of the input image using Gaussian blur and motion blur with randomly generated parameters and randomly chosen part of the input image. The examples of clear images used for testing, and partly distorted versions are shown in Fig. 3. Also developed program in an environment MATLAB, which conducted the segmentation of test images on the described scheme and calculated the segmentation error as the ratio of the number of pixels that were segmented correctly, to the total number of pixels in the image.

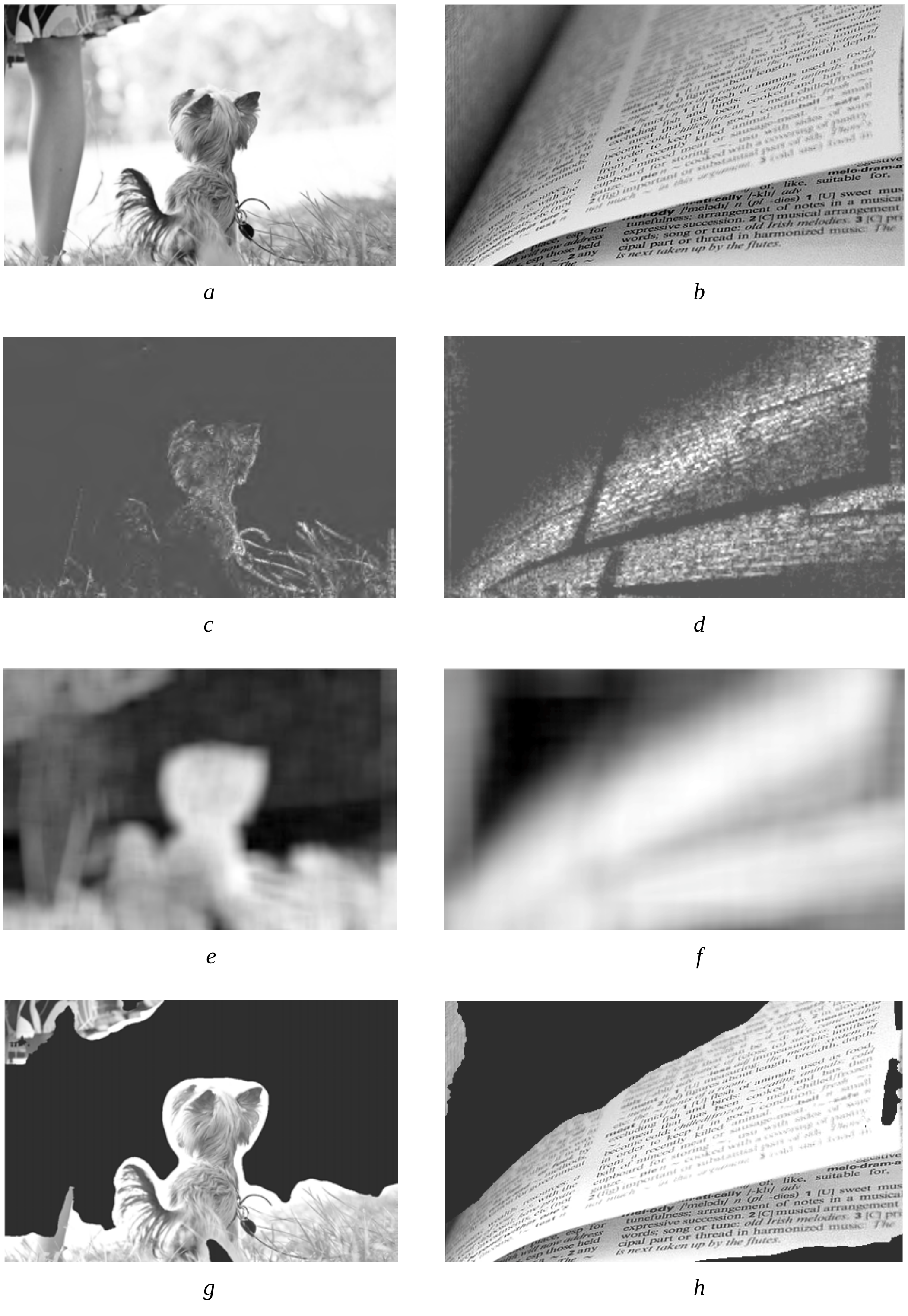

Fig. 2. Result of segmentation and its interim results:
a, b – input image; c, d – edge map by scale of 1 using coiflet of the order L = 3;
e, f – the result of applying the criterion based on the entropy of a window measuring 25×25;
g, h – segmentation result using the method of k-means with two clusters

Of the 84 input images 252 blurred were generated and based on them, according to the algorithm, an average accuracy result is 82%, which is a good result compared to other studies in this domain. Moreover, in many separate cases, the degree of accuracy is higher than 90%.

Conclusion

Developed method for segmenting of partially-blurred (Gaussian blur or motion blur) images using the wavelet transformation, particularly the coiflet of the order L=3, and entropy as a segmentation criterion. The method of *k*-means for image segmentation based on criteria developed is used. Method testing showed good results, namely: the method allows achieving the correct segmentation in average more than 82% of the pixels and in many individual cases – more than 90% of the pixels.

Further work in this area involves the replacement the *k*-means method into more adapted for this domain (for example, using the previous image segmentation by edges with subsequent merging of the segments received), since visual error analysis shows that the *k*-means method does not always allow achieving the desired segmentation.

Fig. 3. Examples of images for testing, the top row shows clear images, and the lower one – partly-blurred versions of the previous images

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