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Automatic Enhancement of Low-Contrast Monochrome Images

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***Abstract*—The problem of images enhancement in automatic mode with an acceptable level of computational costs is considered. The task of adaptive enhancement of integral contrast for complex monochrome images on the basis of their nonlinear statistical non-inertial transformations is considered. The research of the effectiveness of the main histogram-based methods of enhancement of the integral contrast of complex images with low-contrast small-sized objects and non-uniform illumination is carried out. A comparative analysis of the effectiveness of no-reference assessing the generalized contrast of complex images using the histogram-based metrics of integral contrast and on the basis of expert assessments is carried out.**

Keywords—image processing; image quality; contrast enhancement; low-contrast objects; automatic mode

I. Introduction

Currently, the effective enhancement of image quality in automatic mode is extremely relevant for the vast majority of practical applications in image processing, image processing and analysis [1].

Wide applying of modern technologies of imaging and image processing makes the image quality enhancement in automatic mode more relevant than ever [1].

Images enhancement techniques are used to improve the objective quality of an image without its significant distortions, in particular, to improve their visual perception by human beings [2, 3].

At present, various approaches to image enhancement are known [2, 3, 4, 5]. However, it should be noted that now there are no generally accepted and universal methods for image enhancement.

The methodology of image enhancement for known methods usually depends on the context of the specific task being solved, and is most often heuristic [2, 3, 4]. In addition, the criteria for assessing image quality are often subjective and usually based on expert assessments.

Objective quality of image is determined by its basic quantitative characteristics [1, 3, 6]. Complete integral (generalized) contrast is one of the most important quantitative characteristics of the image, which largely determines its objective quality and visual perception [3, 7].

The automatic image enhancement for complex images is currently one of the most pressing and difficult problems in imaging and image pre-processing [1, 3, 4, 5, 6].

The development of new effective techniques of image contrast enhancement in automatic mode with acceptable level of computational costs is especially relevant at present.

In this paper the problem of adaptive enhancement of generalized contrast for complex monochrome images by nonlinear statistical non-inertial transformations is considered (Section II). The subject of the study is histogram-based methods of adaptive contrast enhancement of complex monochrome images in automatic mode. The purpose of the work is research of the effectiveness of the main histogram-based methods of enhancement of the integral contrast of complex images with low-contrast small-sized objects and non-uniform illumination (Sections III, IV and V). The purpose of the work is also a comparative analysis of the effectiveness of no-reference assessing the generalized contrast of complex images using the histogram-based metrics of integral contrast and on the basis of expert assessments.

II. Image Contrast Enhancement

At present, various approaches to image contrast enhancement in automatic mode are known.

The histogram-based methods of nonlinear statistical non-inertial image transformations in the spatial domain are greatest interest for real-time images contrast enhancement in automatic mode, such as [2, 3, 4, 5]:

- methods of adaptive linear stretching [2];
- methods of nonlinear stretching (logarithmic, sigmoid, exponential and power transformations and their modifications, etc.) [2, 3, 4];
- methods of global histogram equalization, histogram specification and its modifications [3, 5].

Linear stretching of brightness in monochrome images is the standard method of improving the contrast of the image, in

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which the dynamic range of brightness of the current image is converted to the range of possible brightness values. The result of linear stretching of the image is most often defined as [2, 4]:

$$L'_i = L'_{\min} + \frac{L'_{\max} - L'_{\min}}{L_{\max} - L_{\min}} \cdot \left(L_i - L_{\min}\right), \quad (1)$$

where L_i, L'_i - values of brightness on initial and transformed image, L_{min}, L_{max} - the minimum and maximum values of brightness on initial image, L'_{min}, L'_{max} - the minimum and maximum values of brightness of transformed image.

In [8], a method of nonlinear stretching of the dynamic range of image brightness is proposed on the basis of the use of the known sigmoid function:

$$L'_i = L'_{\min} + \frac{L'_{\max} - L'_{\min}}{L_{\max} - L_{\min}} \cdot \frac{1}{1 + e^{-\alpha(L_i - \beta)}}, \quad (2)$$

where α, β - parameters of the sigmoid function.

Another known method of non-linear stretching is a piecewise linear transformation of the form [3]

$$L'_i = \begin{cases} 0, & if\ L_i \le L_{\min} \\ \dfrac{k}{b - L_{\min}} \cdot \left(L_i - L_{\min}\right), & if\ L_{\min} < L_i \le b \\ k + \dfrac{1-k}{L_{\max} - b} \cdot \left(L_i - b\right), & if\ b < L_i < L_{\max} \\ 1, & if\ L_i \ge L_{\min} \end{cases}, \quad (3)$$

where k, b - transformation parameters.

In this case, the values of the parameters k and b are often chosen so that the average value of the image brightness is equal to the average value of the range of possible brightness values. Another commonly used standard method of non-linear stretching is gamma correction, which defined by the following power-law expression [2, 4]:

$$L'_i = L'_{\min} + \left(L'_{\max} - L'_{\min}\right) \cdot \left(\frac{L_i - L_{\min}}{L_{\max} - L_{\min}}\right)^{\gamma}, \quad (4)$$

where γ – exponent, parameter.

One of the most widely used methods of image pre-processing is the method of global histogram equalization [5]:

$$L'_i = L'_{\min} + \left(L'_{\max} - L'_{\min}\right) \cdot \int_0^{L_i} p(L)\,dL, \quad (5)$$

where $p(L)$ - probability density function of brightness.

Currently, various modifications to the method of histogram equalization are widely used to images enhancement in the automatic mode.

In [9] a method of contrast enhancement using brightness preserving bi-histogram equalization (BBHE) is proposed in which the histogram is divided into two independent parts relative to the average value of image brightness with subsequent independent equalization of each sub histogram. In [10] a method of dualistic sub image histogram equalization (DSIHE) is proposed in which the histogram is divided into two parts relative to the median value of image brightness.

It should be noted that histogram equalization is a special case of the method of power-law intensification of an image histogram, which is defined as [3, 4]:

$$L'_i = L'_{\min} + \left(L'_{\max} - L'_{\min}\right) \cdot \int_0^{L_i} p^{\gamma}(L)\,dL \Big/ \int_0^{1} p^{\gamma}(L)\,dL. \quad (6)$$

In [11] the histogram-based method of image contrast enhancement on the basis of the estimations of parameters of distribution of brightness values at the boundaries of objects and background is proposed.

These methods (1)-(6), [9], [10] and [11] are widely used to image contrast enhancement in the automatic mode.

III. Research

Research were carried out by a comparative analysis of the results of processing for four test images using ten known histogram-based methods of contrast enhancement, namely:

1) method of linear stretching (1) for $\alpha = 0.01$ [2, 4];
2) method of adaptive sigmoid function (2) [4, 8];
3) method of non-linear stretching for $L_{mean} = 1/2$ (3) [3];
4) method of gamma correction (4) for $\gamma = 0{,}75$ [2, 4];
5) method of gamma correction (4) for $L_{mean} = 1/2$ [2, 4];
6) method of global histogram equalization (GHE) [5];
7) BBHE method [9];
8) DSIHE method [10];
9) method of power-law intensification for $\gamma = 0{,}5$ [3];
10) method of contrast enhancement [11].

Appearance of the four initial images and their histograms is shown in Fig. 1, Fig. 2, Fig. 3 and Fig. 4.

The results of processing the four initial images (Fig. 1, Fig. 2, Fig. 3 and Fig. 4) with using earlier considered methods are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8.

Fig. 1. The first test image A

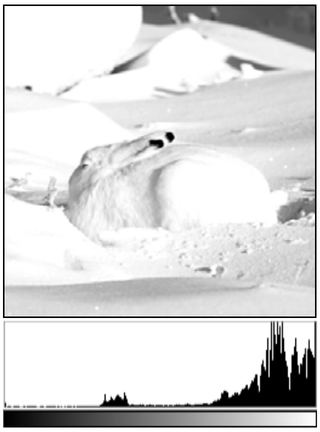


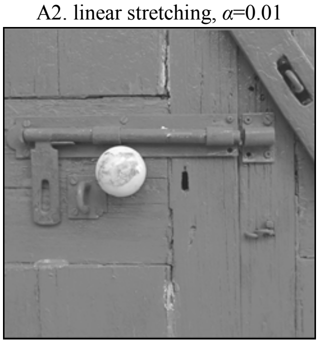
Fig. 2. The second test image B

Fig. 3. The third test image D

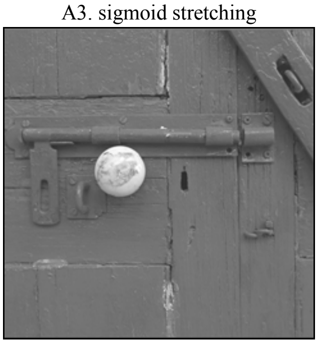
Fig. 4. The fourth test image E

A2. linear stretching, α=0.01

A3. sigmoid stretching



A4. non-linear stretching, L_{mean}=0,5



A5. gamma correction, γ = 0.75

A6. gamma correction, L_{mean}=0,5

A7. histogram equalization, GHE

A8. BBHE method

A9. DSIHE method

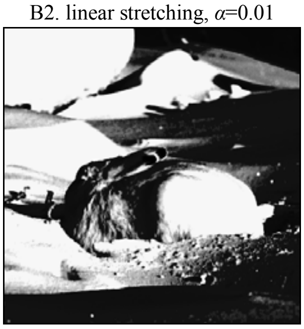
A10. power-law intensification

A11. contrast enhancement [11]

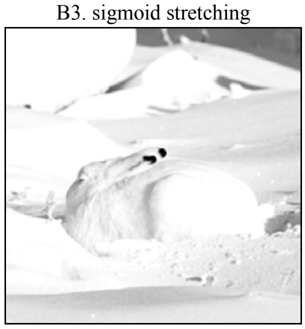
Fig. 5. The results of processing the first test image A.

B2. linear stretching, α=0.01

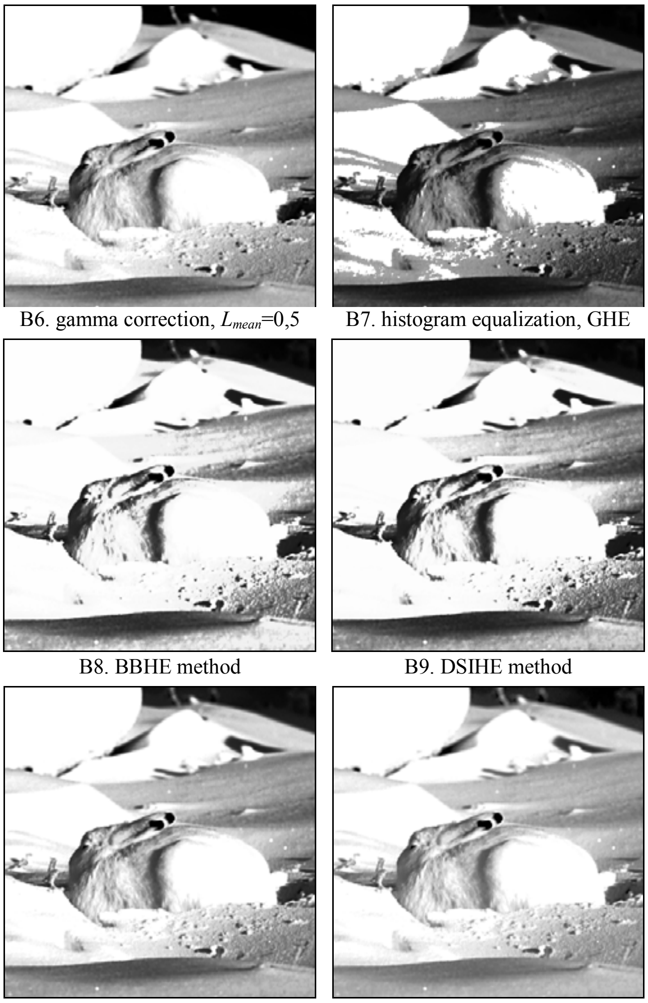
B3. sigmoid stretching



B4. non-linear stretching, L_{mean}=0,5



B5. gamma correction, γ = 0.75

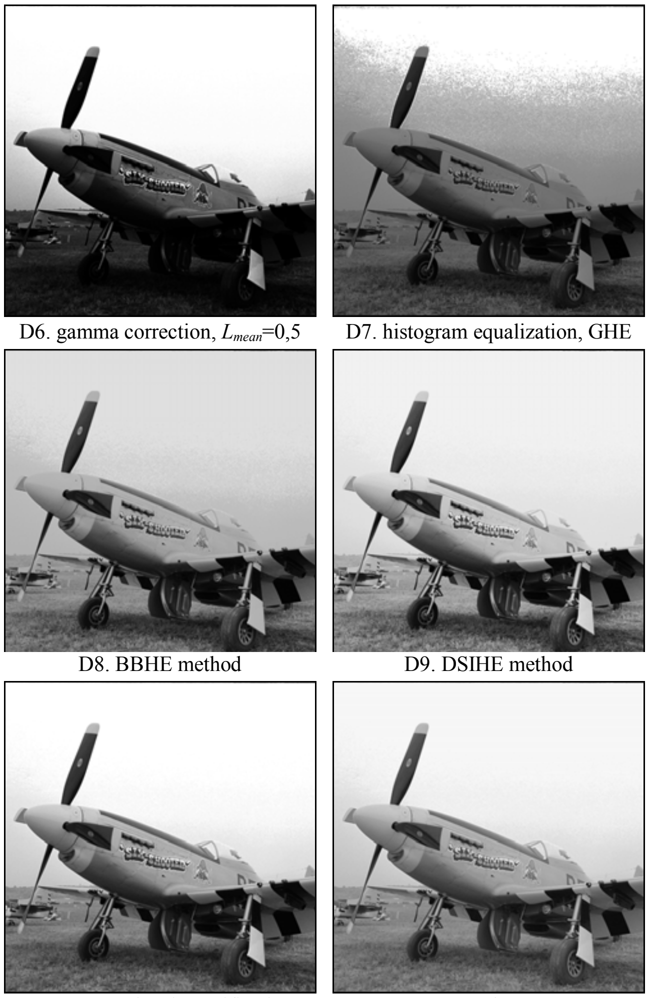


B6. gamma correction, L_{mean}=0,5 B7. histogram equalization, GHE

B8. BBHE method B9. DSIHE method

B10. power-law intensification B11. contrast enhancement [11]

Fig. 6. The results of processing the second test image B.

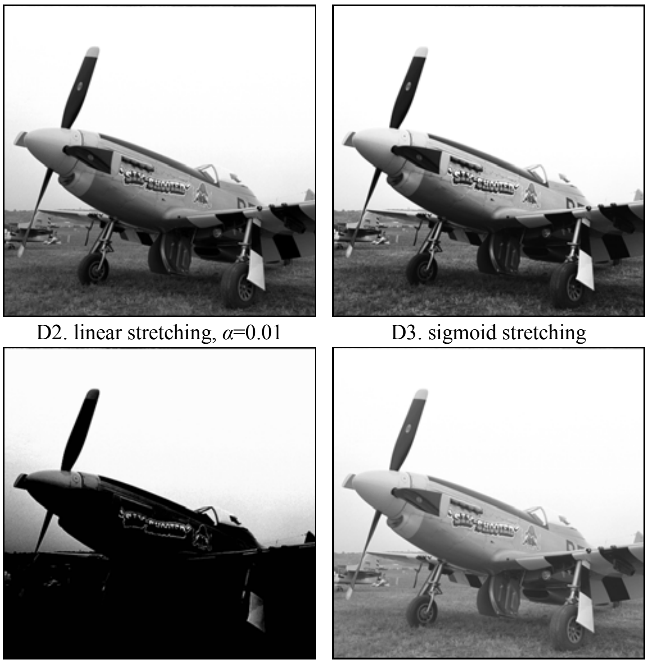


D6. gamma correction, L_{mean}=0,5 D7. histogram equalization, GHE

D8. BBHE method D9. DSIHE method

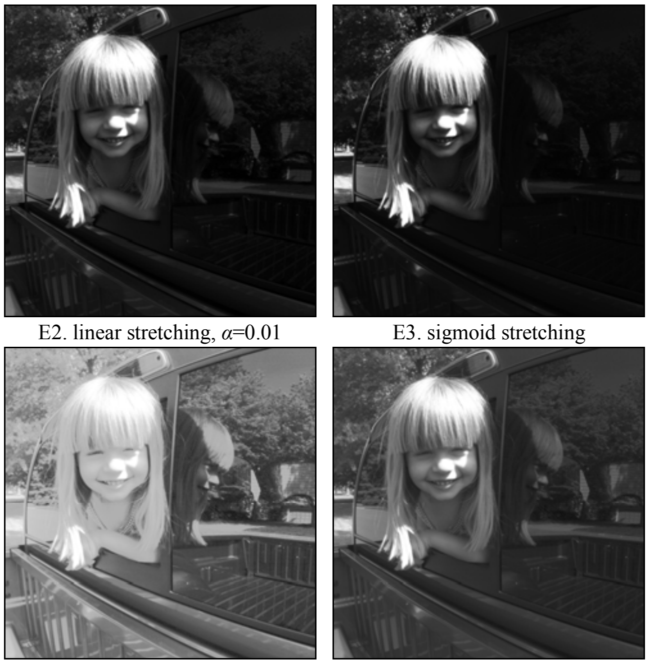
D10. power-law intensification D11. contrast enhancement [11]

Fig. 7. The results of processing the third test image D.



D2. linear stretching, α=0.01 D3. sigmoid stretching

D4. non-linear stretching, L_{mean}=0,5 D5. gamma correction, γ = 0.75



E2. linear stretching, α=0.01 E3. sigmoid stretching

E4. non-linear stretching, L_{mean}=0,5 E5. gamma correction, γ = 0.75

E6. gamma correction, L_{mean}=0,5

E7. histogram equalization, GHE

E8. BBHE method

E9. DSIHE method

E10. power-law intensification

E11. contrast enhancement [11]

Fig. 8. The results of processing the fourth test image E.

Research of the effectiveness of the known methods of contrast enhancement was carried out by measuring of contrast using known no-reference metrics of image contrast.

To measure the image contrast, the known no-reference metrics of integral contrast were used, namely:

1) complete integral (generalized) contrast on the basis of definition of weighted contrast [12]:

$$C_{gen}^{wei} = \int_0^1\int_0^1 \frac{|L_i - L_j|}{L_i + L_j} p(L_i)p(L_j)\, dL_i dL_j \,. \qquad (7)$$

2) incomplete integral contrast for weighted contrast [12]:

$$C_{inc}^{wei} = \int_0^1 \frac{|L_i - L_{mean}|}{L_i + L_{mean}} p(L)dL \,, \qquad (8)$$

where L_{mean} - mean value of image brightness.

3) complete integral contrast on the basis of definition of linear contrast [12]:

$$C_{gen}^{lin} = \int_0^1\int_0^1 \frac{|L_i - L_j|}{L_{pos}} p(L_i)p(L_j)\, dL_i dL_j \,. \qquad (9)$$

where L_{pos} - maximum possible value of brightness.

4) incomplete integral contrast for linear contrast [13]:

$$C_{inc}^{lin} = \int_0^1 \left| \frac{L - L_{mean}}{L_{pos}} + \frac{1}{2} - \left| \frac{L - L_{mean}}{L_{pos}} - \frac{1}{2} \right| \right| p(L)dL \,, \qquad (10)$$

IV. Research Results

Research of the effectiveness of the known methods of contrast enhancement was carried out for four groups of test monochrome images (Fig. 5, Fig. 6, Fig. 7 and Fig. 8) with a complex structure and non-uniform illumination.

The results of measuring of integral contrast for each group of test images (Fig. 5, Fig. 6, Fig. 7 and Fig. 8) are shown in Fig. 9, Fig. 10, Fig. 11 and Fig. 12.

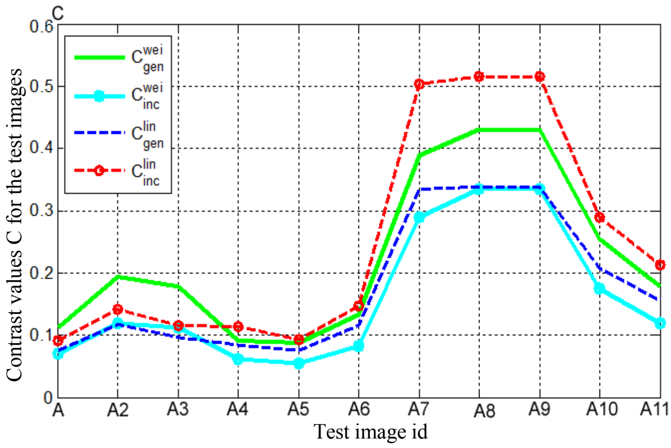


Fig. 9. Results of the measurements for first group of test images

V. Discussion

Analysis of the results of the research shows that the methods of image enhancement in automatic mode by transforming its histogram allow to increase the contrast of complex monochrome images with acceptable level of computational costs.

The research show that the contrast enhancement techniques on the basis of the technology of histogram equalization and its modifications (GHE, BBHE and DSIHE methods) ensure the maximum increase of the integral contrast of the initial image (Fig. 9 and Fig. 12).

However, expert evaluations show that the equalization of histogram can also lead to the suppression of contrast and to the disappearance of small-sized objects on the image, the consequence of which is the reduction of informativity and of the objective quality for some types of complex images (Fig. 6.B7, Fig. 6.B8, Fig. 6.B9, Fig. 7.D7 and Fig. 7.D8).

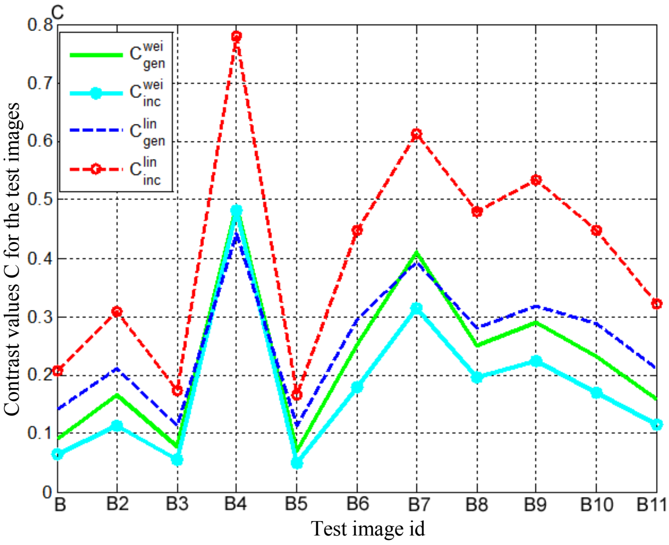


Fig. 10. Results of the measurements for second group of test images

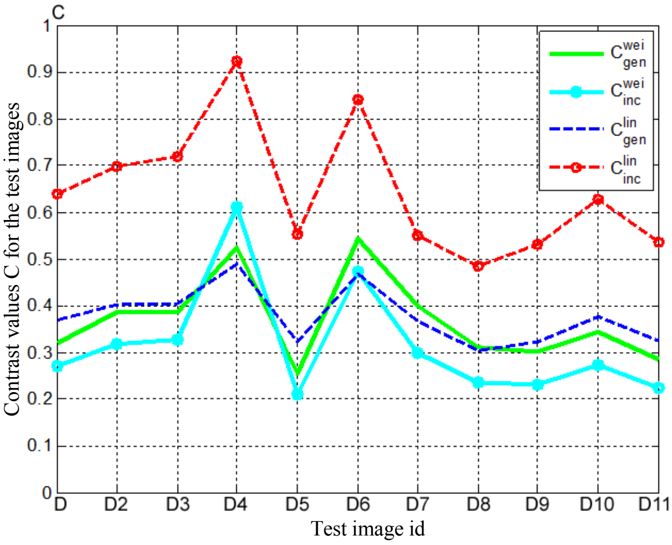


Fig. 11. Results of the measurements for third group of test images

Possible significant reduction of contrast of small-sized objects and excessive increasing of contrast for large-sized objects on image significantly limits the use the technologies of histogram equalization (in particular, GHE, BBHE and DSIHE methods) for processing of complex images in automatic mode.

Efficiency of method of linear stretching essentially depends on the dynamic range of brightness of the initial image and is relatively small for the pre-normalized images (Fig. 3.D, Fig. 7.D2 and Fig. 4.E, Fig. 8.E2).

The effectiveness of the method of non-linear stretching using adaptive sigmoid function depends significantly on the structure of the initial image and the values of parameters of the sigmoid function (Fig. 6.B3, Fig. 8.E3).

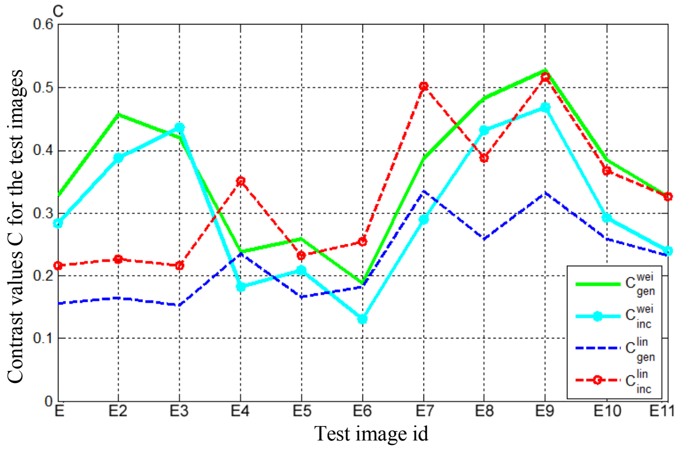


Fig. 12. Results of the measurements for fourth group of test images

The effectiveness of non-linear histogram stretching using piecewise linear transformation depends significantly on the values of parameters of the transformation function (Fig. 6.B4 and Fig. 7.D4).

The effectiveness of gamma correction methods depends significantly on the structure of the initial image and requires the solution of the task of choice the value of parameter gamma in the automatic mode (Fig. 6.B5, Fig. 7.D6).

The methods of power-law histogram intensification (6) and adaptive contrast enhancement [9] provide effective contrast enhancement in automatic mode for all initial images without reducing the contrast of small-sized objects on the image.

VI. Conclusion

In this paper the problem of adaptive enhancement of generalized contrast of low-contrast monochrome images with small-sized objects and non-uniform illumination was considered. The main approaches to the adaptive enhancement of generalized contrast of monochrome images by histogram transformations in automatic mode were considered.

The research of the effectiveness of the main histogram-based methods of increasing the generalized contrast for complex images with low-contrast small-sized objects and non-uniform illumination was carried out.

A comparative analysis of the effectiveness of no-reference assessing the generalized contrast of complex images using the histogram-based metrics of integral contrast and on the basis of expert assessments was carried out.

The research of the effectiveness of the discussed histogram-based methods of image contrast enhancement was carried out for low-contrast monochrome images with small-sized objects and non-uniform illumination.

The results of the research show that the techniques of image enhancement in automatic mode by converting its histogram allow to significantly increase the contrast of complex monochrome images with acceptable level of computational costs. The contrast enhancement techniques on the basis of the technology of histogram equalization and its modifications ensure the maximum increase of the integral contrast of the initial image. However, the technologies for image contrast enhancement by histogram equalization have several significant disadvantages, which significantly limit their practical use. The effectiveness of the methods of the linear and non-linear stretching depends significantly on the structure of the initial image and the values of parameters of the transformation function. The methods of power-law histogram intensification (6) and adaptive contrast enhancement [9] provide effective contrast enhancement in automatic mode and can be recommended for image enhancement in automatic mode.

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