Image Enhancement Technique for Use in Real-Time Mobile Applications

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***Abstract*—This paper addresses the problem of creation of new advanced technologies of image enhancement aimed at use in real-time mobile applications. The aim of this work is to increase the efficiency of image contrast enhancement by gray-level transformations. In order to achieve this aim, we propose a new approach to images enhancement based on an estimate of the brightness distribution at the boundaries of objects in the image. To demonstrate this approach proposes a new parameter-free technique of gray-level transformation for adaptive nonlinear image contrast stretching in automatic mode. The results of experimental research using known no-reference metrics of contrast confirm the effectiveness of the proposed approach.**

Keywords—image enhancement, gray-level transformation, contrast stretching

I. Introduction

Currently, in all developed countries, active works are underway to create and widely introduce new promising technologies for image processing and analysis, aimed at use in various real-time mobile applications. Extensive use of video information requires solving the task of effectively real-time improving the quality of the source raw images [1, 2]. It should be noted that the task of real-time improving the images in mobile gadgets is complex and extremely difficult and additionally imposes a number of peculiar requirements and restrictions to the image processing procedure. Namely, the high efficiency of processing a wide range of images of observed real scenes with different characteristics (integrated brightness, contrast, dynamic range, etc.) for different observation conditions should be ensured. Image transformation and adjust its settings should be carried out in fully automatic mode without operator involvement. In this, the level of computational costs should be minimum for transformations implementation in real-time on low computing power hardware of mobile gadgets. These requirements significantly complicate the use of image processing technologies in real-time mobile applications. Currently there are many different processing techniques, aimed at improving the source images [3, 4, 5]. The best-known approach to image enhancement is to increase its generalized contrast. Contrast enhancement is the classical basic technology in image processing [5] and is widely used to improve the quality and visual perception of the source raw images. Various contrast enhancement techniques are widely used in image pre-processing [6]. Currently, various approaches for contrast enhancement in image are known [3, 5, 6, 7, 8, 9 and 10]. However, the vast majority of known contrast enhancement methods has significant disadvantages and do not satisfy the basic requirements to real-time image processing in automatic mode. The main disadvantages of these known methods are their low efficiency of enhancing the contrast for complex low-contrast images with a wide range of brightness, the emergence of unwanted annoying visual artifacts in the image, the excessively high contrast enhancement of large extended objects, the reduction in contrast for objects with small size, et al. This paper addresses the problem of creation of new technologies of image enhancement that aimed at use in real-time mobile applications. This work deals with the task of effectively increasing the contrast of complex images in an automatic mode. The aim of this work is to increase the efficiency of image contrast enhancement by gray-level transformations. In order to achieve this aim, we propose a new approach to images enhancement based on an estimate of the brightness distribution at the boundaries of objects in the image. To demonstrate this approach proposes a new parameter-free technique of gray-level transformation for adaptive nonlinear image contrast stretching in automatic mode. The results of experimental research using known no-reference metrics of contrast confirm the effectiveness of the proposed approach.

II. Related Works

A lot of works devoted to solving problem of increasing the contrast of images are currently known [3-6, 8, 9 and 10]. In this, methods of image processing in the spatial domain based on gray-level transformations are of particular interest for real-time applications. Distinctive feature of these methods are their high efficiency and simplicity of implementation. Existing methods of image contrast enhancement by gray-level transformations can be conditionally subdivided into three basic groups, namely contrast stretch techniques, basic gray-level transformations and histogram specification techniques [3, 5, 6 and 10]. The well-known methods of contrast stretching (partial [5, 10], min-max [3, 5], percentage [3, 10] and piecewise [5, 10] linear stretching) carry out linear stretching of the selected sub-range of the brightness scale. Contrast stretching methods allow an increase in the contrast of simple images with a narrow dynamic range. A significant disadvantage of the methods based on linear contrast stretching is their low efficiency of processing for complex images with a wide range of brightness values. Another group of image enhancement techniques are based on basic nonlinear transformations of brightness scale (e.g. logarithmic [3, 5], exponential [3, 5] and power-law [5] transformations, gamma correction [11, 12 and 13], sigmoid transformations [14], etc.). The results of contrast enhancement using these basic gray-level transformations significantly depend on the choice of the type and the values of parameters of the transformation and on the main characteristics (on integrated brightness, contrast, dynamic range) of the source image.

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The third group includes the methods based on histogram specification technique and its modifications. Currently, histogram specification is the most widely used approach to images enhancement by gray-level transformations [15, 16 and 17]. The histogram specification (also know as a histogram mapping) is a transformation at which the brightness distribution in image takes a specified shape and matches the brightness distribution in the reference image [15]. Most often it is assumed that the brightness of reference image have uniform, exponential, hyperbolic, Gaussian, Rayleigh or Poisson distribution [3, 5]. The implementation of the procedure of histogram specification is reduced to the histogram equalization for the source and reference image with the subsequent matching of the obtained results [15]. Histogram equalization is the most known used approach to histogram specification, in which it is assumed that the desired brightness in a reference image is uniformly distributed [18]. Histogram equalization is currently the most well-known contrast enhancement technique and is a standard procedure in image pre-processing. Various histogram equalization based techniques are very widely applied for image processing in automatic mode owing to its high effectiveness and simplicity of implementation. Another well-known technique of image enhancement is sub image histogram equalization [19, 20 and 21]. In this case, the dynamic range of image separate into a number of sub-ranges for each of which the histogram equalization is performed. Histogram equalization based techniques are characterized by high efficiency and simplicity of implementation and are currently are very popular. However, known methods of image processing based on histogram equalization have several disadvantages. The main disadvantages of histogram equalization are the reduction in contrast for objects with small size, the excessively high contrast enhancement of large extended objects and the emergence of unwanted annoying visual artifacts in the image. The above disadvantages significantly complicate the use of histogram equalization based techniques for real-time image processing in automatic mode. To enhance the image contrast without the emergence any unwanted artifacts, we propose a new approach to adaptive nonlinear image contrast stretching based on gray-level transformation technique.

III. Proposed Approach

In this paper, proposes a new approach to image gray-level transformation based on an estimate of the brightness distribution at the boundaries of objects in the image.

Suppose that the gray-level transformation of image has the form:

$$y = y_{\min} + \left(y_{\max} - y_{\min}\right) \cdot F\left(x\right), \qquad (1)$$

where x and y - values of brightness in source and transformed images; y_{min} and y_{max} – minimum and maximum brightness in the transformed image; $F(x)$ – gray-level transformations function.

In (1) it is assumed that:

$$0 \le x_{\min} \le x \le x_{\max} \le 1\,,\; x_{\min} < x_{\max}\,, \qquad (2)$$

$$0 \le y_{\min} \le y \le y_{\max} \le 1\,, \qquad (3)$$

$$0 \le F\left(x\right) \le 1, \forall x \mid x_{\min} \le x \le x_{\max}\,, \qquad (4)$$

where x_{min} and x_{max} - minimum and maximum gray levels in the source image.

The function $F(x)$ is a statistical no-inertial transformation of the brightness values in the source image. To enhance the source image, we propose an adaptive nonlinear transformation $F(x)$ which is defined as the integral transformation in the form of:

$$F\left(x\right) = \alpha \cdot \int_0^x \varphi\left(u\right) \cdot \left[\varphi\left(1\right) - \varphi\left(u\right)\right] du\,, \qquad (5)$$

$$\alpha = \left[\int_0^1 \varphi\left(u\right) \cdot \left[\varphi\left(1\right) - \varphi\left(u\right)\right] du\right]^{-1}, \qquad (6)$$

where $\varphi(\cdot)$ – assessment of the brightness distribution at the boundaries of objects in an image; α - normalizing factor.

Expressions (1), (4) and (5) define the proposed approach to image enhancement. To demonstrate the proposed approach (5), suppose that the assessment of brightness distribution $\varphi(\cdot)$ is defined as:

$$\varphi\left(u\right) = \beta \cdot \int_0^u p\left(x\right)^{\gamma} dx\,,\;\; \beta = \left[\int_0^1 p\left(x\right)^{\gamma} dx\right]^{-1}, \qquad (7)$$

where β – normalizing factor, γ – parameter, exponent.

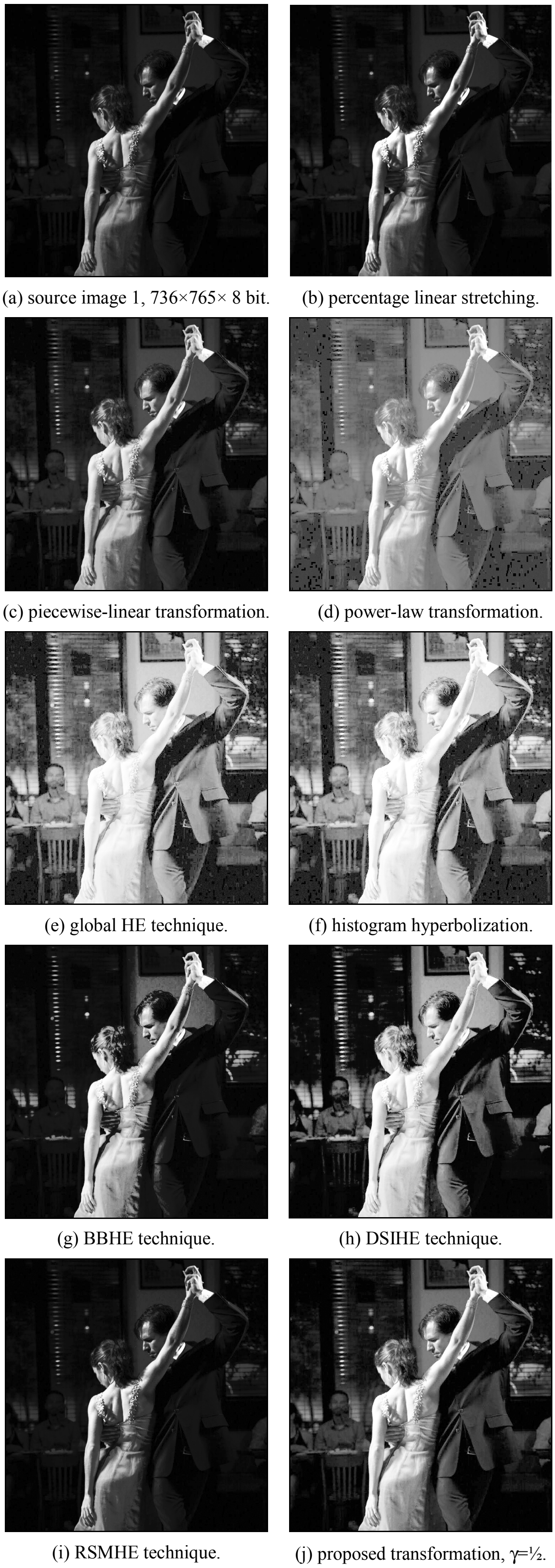
The proposed image contrast enhancement technique is defined in accordance with (1), (5)-(7).

IV. Experimental Results

Experimental research is carried out by comparative analysis of the results of processing of test images using various techniques of gray-level transformation, namely:

- percentage linear contrast stretching [10];
- piecewise-linear contrast stretching [22];
- power-law transformation (gamma correction) for $y_{mean} = ½$ [5, 13];
- global histogram equalization technique (HE) [5, 18];
- histogram hyperbolization technique [23];
- BBHE technique [24];
- DSIHE technique [25];
- RSMHE technique [26];
- proposed gray-level transformation (1), (5) – (7).

Test images and the results of their processing in spatial domain using the known and proposed gray-level transformations techniques are presented in Fig. 1 - Fig. 4. Evaluation of the results of images processing was carried out by measuring integral contrast of the transformed image using known no-reference metrics of contrast.



(a) source image 1, 736×765× 8 bit. (b) percentage linear stretching.

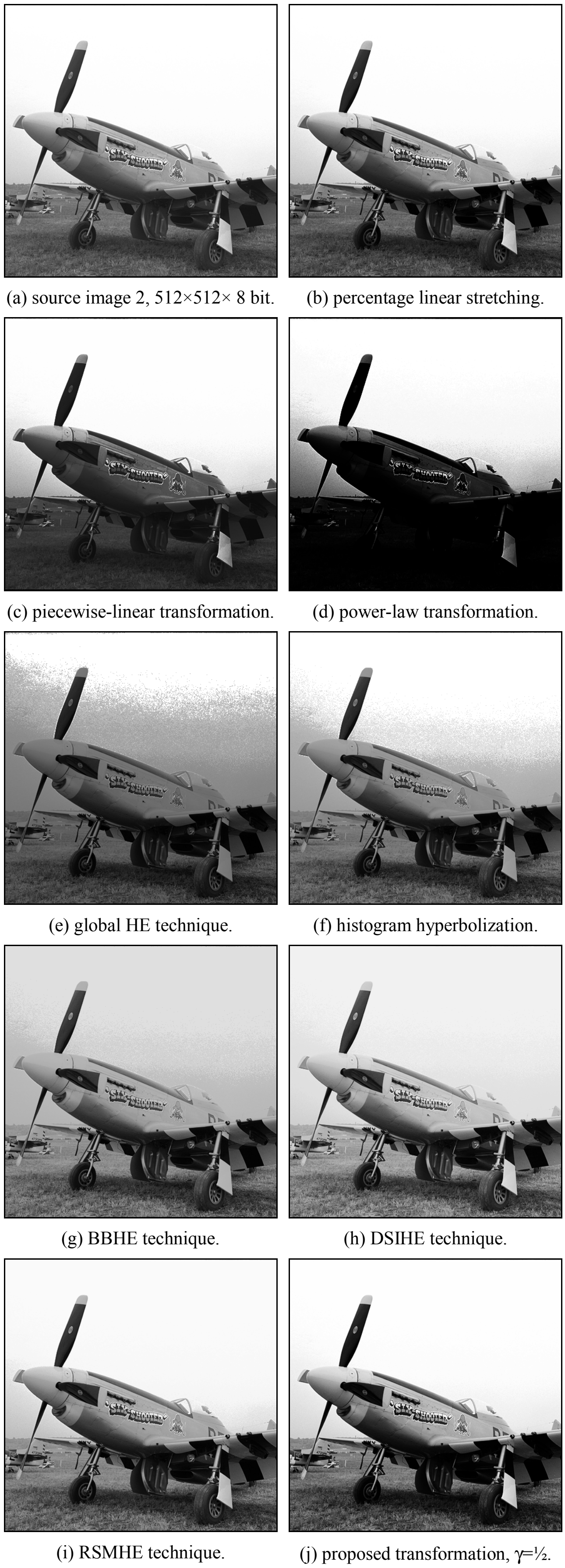
(c) piecewise-linear transformation. (d) power-law transformation.

(e) global HE technique. (f) histogram hyperbolization.

(g) BBHE technique. (h) DSIHE technique.

(i) RSMHE technique. (j) proposed transformation, γ=½.

Fig. 1. Results of gray-level transformations for image 1.



(a) source image 2, 512×512× 8 bit. (b) percentage linear stretching.

(c) piecewise-linear transformation. (d) power-law transformation.

(e) global HE technique. (f) histogram hyperbolization.

(g) BBHE technique. (h) DSIHE technique.

(i) RSMHE technique. (j) proposed transformation, γ=½.

Fig. 2. Results of gray-level transformations for image 2.

a) source image 3, 750×750× 8 bit.

(b) percentage linear stretching.

(c) piecewise-linear transformation.

(d) power-law transformation.

(e) global HE technique.

(f) histogram hyperbolization.

(g) BBHE technique.

(h) DSIHE technique.

(i) RSMHE technique.

(j) proposed transformation, γ=½.

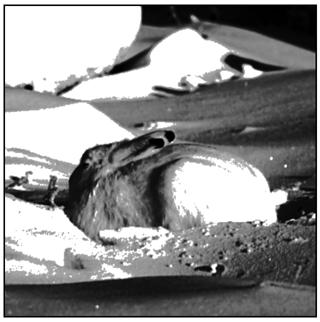
Fig. 3. Results of gray-level transformations for image 3.

(a) source image 4, 400×400× 8 bit.

(b) percentage linear stretching.

(c) piecewise-linear transformation.

(d) power-law transformation.



(e) global HE technique.

(f) histogram hyperbolization.

(g) BBHE technique.

(h) DSIHE technique.

(i) RSMHE technique.

(j) proposed transformation, γ=½.

Fig. 4. Results of gray-level transformations for image 4.

To measure the contrast of transformed image, known no-reference metrics of image contrast were used, such as:

- complete integral contrast for linear kernel [27]:

$$C_{gen}^{lin} = \int_0^1 \int_0^1 \frac{|x_n - x_m|}{x_{\max} - x_{\min}} \cdot p(x_n) \cdot p(x_m)\, dx_n dx_m \qquad (8)$$

- mean value of the squares of the differences in brightness values for all pairs of image elements [28]:

$$C_{gen}^{dif} = \int_0^1 \int_0^1 (x_n - x_m)^2 \cdot p(x_n) \cdot p(x_m)\, dx_i dx_j\,, \qquad (9)$$

- incomplete integral contrast for linear kernel [29]:

$$C_{inc}^{lin} = \int_0^1 \frac{|x - x_0|}{x_{\max} - x_{\min}} \cdot p(x) dx\,, \qquad (10)$$

- standard deviation (STD) [30]:

$$STD = \left[\int_0^1 (x - x_0)^2 \cdot p(x) dx \right]^{1/2}. \qquad (11)$$

The values of contrast estimates using no-reference metrics (8) - (11) for transformed images (Fig. 1 - Fig. 4) are presented in Fig. 5 - Fig. 8.

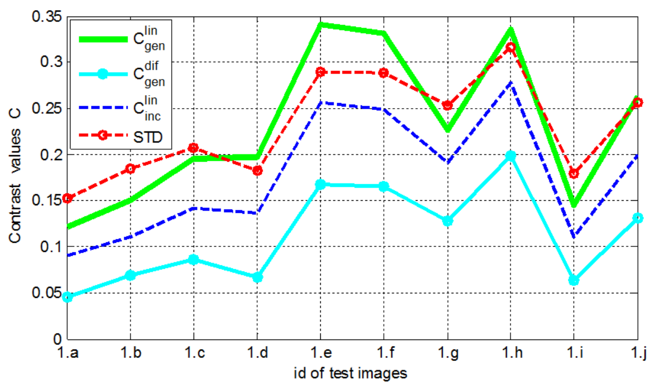


Fig. 5. Contrast values for transformed images (Fig. 1).

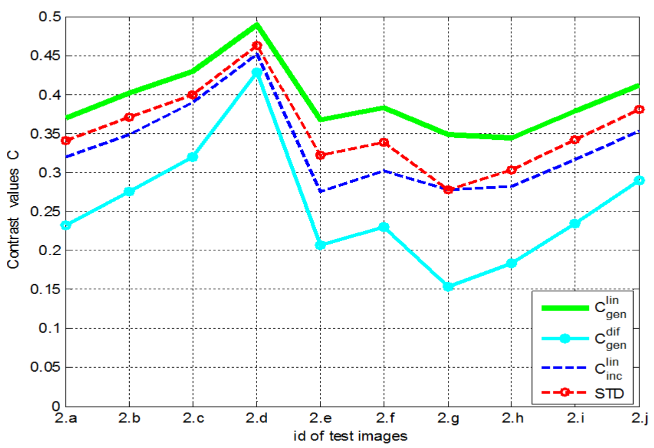


Fig. 6. Contrast values for transformed images (Fig. 2).

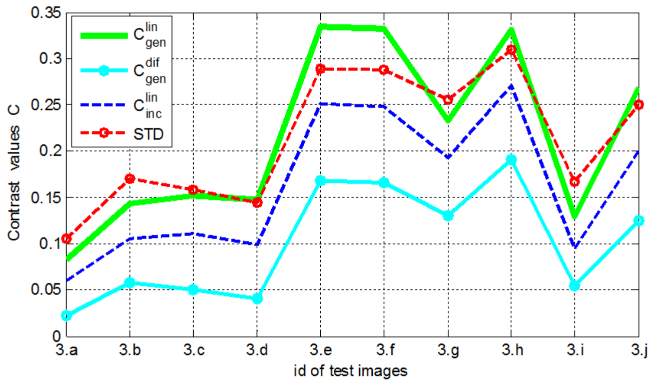


Fig. 7. Contrast values for transformed images (Fig. 3).

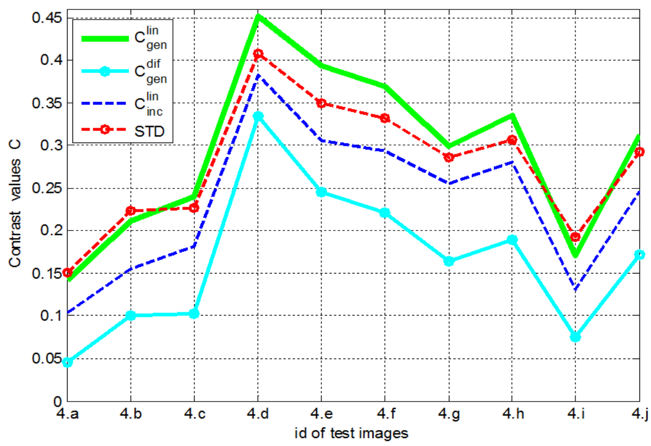


Fig. 8. Contrast values for transformed images (Fig. 4).

V. Discussion

The research show that partial contrast stretching techniques allow an increase in the contrast of simple images with a narrow dynamic range (Fig. 4b), however, they are ineffective for processing of images with a wide range of brightness values (Fig. 1b, Fig. 2b and Fig. 3b). The efficiency of piecewise linear contrast stretching (Fig. 1c, Fig. 2c, Fig. 3c and Fig. 4c) depends heavily on the brightness distribution and on choice of parameters (threshold values) for the piecewise linear transformation and is comparatively low for low-contrast images with a wide range of brightness values (Fig. 1c, Fig. 2c and Fig. 3c). The efficiency of basic gray-level transformations is decisively determined by the choice of the type and the values of parameters of the transformation. Thus, inefficient choice of the values of transformation parameters can lead to a significant deterioration in the visual perception of the image and the emergence of unwanted artifacts in the image (Fig. 2d and Fig. 4d). The research shows that methods based on histogram equalization technology and its modifications (BBHE, DSIHE, RSMHE) provide effective enhance of images in automatic mode (Fig. 5 and Fig. 7). The histogram equalization based technique allows significantly improve the quality of complex images with a wide range of brightness values (Fig.1e, Fig.1f, Fig.1h, Fig.3e, Fig.3f and Fig.3h) and is characterized by high efficiency, low level of computational cost and simplicity of real-time implementation. However, the research shows that known methods of image processing based on histogram equalization can result in the reduction in contrast for objects with small size, the excessively high enhancement of contrast for large extended objects and the emergence of unwanted artifacts in the image, which may lead to significant deterioration in the quality and visual perception of the transformed image (Fig. 2e, Fig. 2f and Fig. 4e). This significantly complicate the use of histogram equalization based techniques for real-time image processing in automatic mode. The proposed image enhancement technique by adaptive nonlinear contrast stretching (1), (5)-(7) allows to effectively increase the integral contrast of the image due to a more even distribution of the contrast of objects in the image without the emergence of unwanted artifacts (Fig. 1j, Fig. 2j, Fig. 3j and Fig. 4j). The proposed nonlinear contrast stretching technique provides an increase in the integral contrast of images by an average of 86% - 138% compared with the source images and a more even distribution of contrast in the image by redistributing the contrast of low-contrast objects and objects with excessively-high contrast. The proposed technique (1), (5)-(7) is characterized by high efficiency, simplicity of implementation, has a low computational cost and is aimed at use in mobile gadgets for real-time image pre-processing.

VI. CONCLUSIONS

In this paper, the problem of creating new advanced technologies of image enhancement that aimed at use in real-time mobile applications was considered. The aim of this work was to increase the efficiency of image contrast enhancement by gray-level transformations.

A new approach to images enhancement by statistical non-inertial transformation of brightness scale based on an estimate of the brightness distribution at the boundaries of objects in the image was proposed. The proposed approach provides an increase in the contrast of complex images and a more even distribution of contrast in the image by redistributing the contrast of low-contrast objects and objects with excessively-high contrast. A new parameter-free technique of gray-level transformation for adaptive nonlinear image contrast stretching in automatic mode was proposed. The proposed nonlinear contrast stretching technique provides an effectively increase in the integral contrast of images compared with the source images without the emergence of unwanted artifacts. The results of experimental research using known no-reference metrics of contrast confirm the effectiveness of the proposed approach. The proposed technique is characterized by low level of computational cost and simplicity of real-time implementation and is aimed at use in mobile gadgets.

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