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ОЦІНКА УЗАГАЛЬНЕНОГО КОНТРАСТУ МОНОХРОМНИХ ЗОБРАЖЕНЬ БЕЗ ВИКОРИСТАННЯ ПОСИЛАНЬ

Розглянуто проблему вимірювання без посилань узагальненого (повного інтегрального) контрасту складних (багатоелементних) монохромних зображень для об'єктивного оцінювання їх якості. Розглянуто різні підходи до кількісного оцінювання узагальненого контрасту складного монохромного зображення на основі аналізу значень контрасту елементів зображення відносно заданого рівня адаптації. Вирішується завдання вимірювання контрасту двох елементів зображення (об'єктів та фону) при заданому значенні рівня адаптації. Запропоновано новий метод вимірювання контрасту двох елементів зображення відносно заданого рівня адаптації з використанням різних визначень ядра контрасту. Запропоновано нові визначення зваженого та абсолютного контрасту двох елементів зображення відносно заданого рівня адаптації. Запропоновано нові визначення узагальненого та неповного інтегрального контрасту монохромного зображення для зваженого та абсолютного ядер контрасту. Досліджено відомі та запропоновані визначення для узагальненого та неповного інтегрального контрасту монохромного зображення з використанням зваженого та абсолютного ядер контрасту.

Ключові слова: якість зображення, контраст, ядро контрасту, узагальнений контраст, неповний інтегральний контраст.

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NO-REFERENCE ASSESSMENT OF THE GENERALIZED CONTRAST OF COMPLEX MONOCHROME IMAGES

The problem of no-reference measurement of generalized (full integral) contrast of complex (multi-element) monochrome images for objective assessment of their quality is considered in this paper. Different approaches to the quantitative assessment of the generalized contrast of a complex monochrome image on the basis of an analysis of the contrast values of image elements relative to a preset level of adaptation are considered. The task of measuring the contrast of image elements (objects and background) for a preset adaptation level is solved. A new method of measuring the contrast of two image elements for a preset adaptation level using various definitions of the contrast kernel is proposed. New definitions of the weighted and absolute contrast of two image elements for a preset adaptation level are proposed. New definitions of generalized contrast and incomplete integral contrast of a monochrome image for weighted and absolute contrast are proposed. A comparison of proposed and known definitions of generalized contrast and of incomplete integral contrast of monochrome image for weighted and absolute contrast of image elements is carried out.

Key words: image quality, contrast, contrast kernel, generalized contrast, incomplete integral contrast

Introduction

Nowadays the operative (in real-time) quantitative assessment (measurement) of objective quality of images is one of the most urgent and difficult problems for the vast majority of practical applications in imaging, image processing and analysis [1, 2]. Wide applying of modern technologies of imaging and image processing makes no-reference assessment of the objective quality of the formed images more relevant than ever [3]. Objective quality of image is defined on the basis of main quantitative characteristics (parameters) of current image [3, 4]. The main characteristic, which largely determines the objective quality of the image as a whole, is its generalized contrast [5, 6]. At present, however, quantitative assessment and measurement of values of generalized contrast for complex images are not defined uniquely in the literature. In addition, the known definitions of contrast have number significant shortcomings that significantly limit their practical use [6, 7]. For elimination of these shortcomings the new definitions of generalized contrast and of incomplete integral contrast on the basis of new method of measuring the contrast of image elements relative to a preset level of adaptation is proposed.

The object of study is the process of contrast measurement for image quality assessment. The problem of developing of histogram-based methods of no-reference measurement of generalized contrast for complex images is considered in this paper (Section 2). Different approaches to the contrast measurement of a complex image on the basis of an analysis of the contrast of image elements relative to a preset level of adaptation are also considered. The purpose of the work is to increase the accuracy of measurement the contrast of complex images by development of new method of measuring the contrast of image elements relative to a preset adaptation level. The subject of the study is histogram-based methods of no-reference measurement of contrast of complex images. In this paper the new method of measuring the contrast of two image elements for a preset adaptation level using various definitions of the contrast kernel is proposed (Section 3). New definitions of the weighted and absolute contrast of two image elements for a preset adaptation level are proposed. New definitions of generalized contrast and incomplete integral contrast of a monochrome image for weighted and absolute contrast are also proposed. The research for known and proposed definitions of generalized contrast and of incomplete integral contrast of monochrome image on compliance with the basic requirements to the definition of contrast using weighted and relative contrast kernels is carried out (Section 4 and Section 5).

1. The contrast measurement of complex images

The contrast measurement for complex images is usually carried out by analyzing of contrast values for all individual pairs of adjacent elements in the image (of objects and background) [5]. The contrast of two adjacent elements of the image (two objects or an object and a background) characterizes the difference in the values of their brightness [6]. It should be noted, however, that the unambiguous and generally accepted definition of the generalized contrast for complex images is currently unknown.

The choice of definitions of generalized contrast and contrast of image elements (often called the kernels of contrast) is a very difficult problem and largely determines the efficiency (accuracy) of the quantitative assessment (of measuring) of the contrast value for complex images [6, 7].

It is traditionally assumed that contrast is a dimensionless function and satisfies the basic requirements to contrast definition [6, 7].

2. The basic requirements to the contrast definition

The contrast C_{ij} of two adjacent elements i and j of the current image is a dimensionless function of the values B_i and B_j of their brightness. As a rule, it is assumed that the definition of contrast satisfies the following basic requirements [6, 7]:

1) Conditions of equal influence of arguments and symmetry of properties of change of absolute values of contrast:

$$\left| C_{ij} \right| = \left| C_{ji} \right|, \tag{1}$$

$$C_{ij} = -C_{ji}. \tag{2}$$

The sign of contrast indicates which of the values predominates, B_i or B_j.

2) Conditions of uniqueness and definiteness of the conditions under which the equality to zero is achieved:

$$\left|C_{ij}\right| = 0, \ \textit{only when} \ B_i = B_j . \tag{3}$$

The value of contrast must be equal to zero for (only when) equal values of B_i and B_j.

3) The definiteness and unambiguous of the conditions under which the absolute value of the contrast reaches its maximum value. The maximum contrast value of the absolute values of contrast should correspond to the maximum difference between the brightness values:

$$\left| C_{ij} \right| \to \begin{cases} = \left|C_{\max}\right|, & \textit{if} \ \left|B_i - B_j\right| = B_{\max} - B_{\min} \\ < \left|C_{\max}\right|, & \textit{if} \ \left|B_i - B_j\right| < B_{\max} - B_{\min} \end{cases}, \tag{4}$$

where C_{max} – maximum value of contrast, B_{min}, B_{max} – minimum and maximum brightness values of elements of the current image.

4) The contrast has a limited range of values. It is usually assumed that the change of the absolute values of contrast is limited by the range [0, 1]:

$$\left|C_{ij}\right| \in [0, 1]. \tag{5}$$

Expressions (1)–(5) determine the basic requirements to definition the contrast of image elements.

3. The contrast of complex image

Various approaches to the quantitative assessment of the contrast of complex images are now known [3, 5]. However, it must be noted that the unambiguous and generally accepted definition of the contrast for complex images is currently unknown.

The generalized contrast of a complex image can be defined as the averaged value of the contrast values of all pairs (*i, j*) of adjacent elements in the current image:

$$C_{gen} = \int_{-1}^{1} \left|C_{ij}\right| \cdot p(C_{ij}) dC_{ij} . \tag{6}$$

where C_{ij} – contrast value of two image elements; $p(C_{ij})$ – probability density of values of contrast C_{ij}.

But for the calculation of $p(C_{ij})$ it is needed to be addressed the problem of detecting the boundaries of image elements, that in itself is quite a complex and resource intensive task [4, 8].

In [5], it was proposed the quantitative assessment for the complete integral (generalized) contrast of complex multi-element image as an average value of the contrast values of image elements relative to a preset adaptation level for all pairs of adjacent elements in current image:

$$C_{gen} = \int_{-1}^{1} \left|C_{ij0}\right| \cdot p\left(C_{ij0}\right) dC_{ij0}, \tag{7}$$

$$C_{gen} = \int_{0}^{1}\int_{0}^{1} \left|C_{ij0}\right| \cdot p\left(B_i, B_j\right) dB_i dB_j . \tag{8}$$

where C_{ij0} – contrast of an elementary two-element image with brightness B_i and B_i relative to the preset level of adaptation B_0; $p(C_{ij0})$ – probability density of contrast C_{ij0} for all possible pairs B_i and B_j in the image; $p(B_i,B_j)$ – two-dimensional distribution of brightness of image elements; B_0 – preset value of adaptation level, which is equal to the average value of image brightness [5, 6], $B_0 = \overline{B}$, $\overline{B} = mean(B)$:

$$B_0 = \overline{B} = \int_{0}^{1} B \cdot p(B) dB . \tag{9}$$

where $p(B)$ – probability density of image brightness B.

It should be noted that for the practical implementation of this approach (8) it is necessary to solve a number of rather complicated problems [5]. In particular, it is necessary to solve the problems of choosing

the contrast definition of two image elements relative to a preset adaptation level, of choosing a method to estimate the values of the two-dimensional distribution of brightness of image elements and of choosing the value of adaptation level B_0 for current image.

In [5] the definition of contrast of an elementary two-element image relative to the preset adaptation level was proposed:

$$C_{ij0} = \left(C_{i0} + C_{j0}\right)/\left(1 + C_{i0} \cdot C_{j0}\right), \tag{10}$$

where C_{ij0} – contrast of *i*-th and *j*-th elements in image with the preset adaptation level B_0; C_{i0}, C_{j0} – contrast values of image element relative to the value B_0 of adaptation level.

For this case [5], the contrast of current image element relative to the value of the adaptation level B_0 was defined as:

$$C_{i0} = \left(B_i - B_0\right)/\left(B_i + B_0\right) \text{ and } C_{j0} = \left(B_j - B_0\right)/\left(B_j + B_0\right), \tag{11}$$

on the basis of the well-known definition of the weighted contrast of two image elements (of the weighted contrast kernel) [8]:

$$C_{ij}^{wei} = \left(B_i - B_j\right)/\left(B_i + B_j\right). \tag{12}$$

In this case, the expressions (10) and (8) using (11) takes the form [5]:

$$C_{ij0}^{wei} = \left(B_i \cdot B_j - B_0^2\right)/\left(B_i \cdot B_j + B_0^2\right), \tag{13}$$

$$C_{gen}^{wei} = \int_0^1 \int_0^1 \left| \left(B_i \cdot B_j - B_0^2\right)/\left(B_i \cdot B_j + B_0^2\right) \right| \cdot p\left(B_i, B_j\right) dB_i dB_j . \tag{14}$$

Expression (14) [5] is the definition of the complete integral contrast (generalized) for a complex image on the basis of the well-known definition of kernel of weighted contrast [8].

It should be noted that the estimation (measurement) of the values of the two-dimensional distribution $p(B_i,B_j)$ of the brightness is a rather complex and resource-consuming task [4, 5]. Various approaches to the estimation of the values of the two-dimensional brightness distribution are known [5, 10].

For the case where image elements are independent events in relation to each other, it can be suggested that two-dimensional distribution $p(B_i,B_j)$ has the form [5, 9]:

$$p\left(B_i, B_j\right) = p\left(B_i\right) \cdot p\left(B_j\right). \tag{15}$$

In this case, the expressions (8) and (14) taking into account (15) can be described in the form [5, 9]:

$$C_{gen} = \int_0^1 \int_0^1 \left|C_{ij0}\right| \cdot p\left(B_i\right) \cdot p\left(B_j\right) dB_i dB_j , \tag{16}$$

$$C_{gen}^{wei} = \int_0^1 \int_0^1 \left|\left(B_i \cdot B_j - B_0^2\right)/\left(B_i \cdot B_j + B_0^2\right)\right| \cdot p\left(B_i\right) \cdot p\left(B_j\right) dB_i dB_j . \tag{17}$$

In [5], in order to reduce computational costs, the following estimate of the values of two-dimensional distribution $p(B_i,B_j)$ of the image brightness was proposed:

$$p\left(B_i, B_j\right) = p\left(B_i\right) \cdot \delta\left(B_i - B_j\right), \tag{18}$$

where $\delta(\cdot)$ – delta function.

For this case, on the basis of (8), (13) and (18), the definitions of the incomplete integral contrast of image were also proposed [5]:

$$C_{\Sigma} = \int_0^{\infty} \left|C_{ii0}\right| \cdot p\left(B_i\right) dB_i , \tag{19}$$

$$C_{ii0} = 2C_{i0}/\left(1 + C_{i0}^2\right), \tag{20}$$

$$C_{ii0}^{wei} = \left(B_i^2 - B_0^2\right)/\left(B_i^2 + B_0^2\right), \tag{21}$$

$$C_{\Sigma}^{wei} = \int_0^1 \left|B_i^2 - B_0^2\right|/\left(B_i^2 + B_0^2\right) \cdot p\left(B_i\right) dB_i . \tag{22}$$

The known expressions (16) and (19) are no-reference histogram-based metrics of generalized contrast and of incomplete integral contrast for complex monochrome images [5]. The known expressions (17) and (22) are definitions of generalized contrast and of incomplete integral contrast on the basis of definition (12) of weighted contrast kernel.

In the definition (10), the contrast C_{i0} of the two elements (of image object and of the adaptation level of image) was defined in a generalized form. At present, various approaches to measuring the contrast value for two image elements are known which can be used to measure the contrast of an image element relative to a preset adaptation level.

Consider the definition of the contrast of an elementary two-element image (10) for the case of using the known definition of kernel of absolute contrast [6]. The generalized definition of absolute contrast can be described in the form:

$$C_{ij}^{abs} = \alpha \cdot \left(B_i - B_j\right). \tag{23}$$

where α - normalizing factor, multiplier.

The value of the normalizing coefficient α is most often taken equal to [6]:

$$\alpha = BMAX^{-1} \quad and \quad C_{ij}^{abs} = \left(B_i - B_j\right)/BMAX\ , \tag{24}$$

or equal to [7]:

$$\alpha = \left(B_{\max} - B_{\min}\right)^{-1} \quad and \quad C_{ij}^{abs} = \left(B_i - B_j\right)/\left(B_{\max} - B_{\min}\right), \tag{25}$$

where *BMAX* - maximum possible brightness value.

Then, by analogy with (13), the absolute contrast of an elementary two-element image relative to the preset level of adaptation is equal to:

$$C_{ij0}^{abs} = \alpha \cdot \left(B_i + B_j - 2B_0\right)/\left(1 + \alpha^2 \cdot \left(B_i - B_0\right) \cdot \left(B_j - B_0\right)\right). \tag{26}$$

In this case, the generalized absolute contrast of image has the form:

$$C_{gen}^{abs} = \int_0^1 \int_0^1 \left| \alpha \cdot \left(B_i + B_j - 2B_0\right)/\left(1 + \alpha^2 \cdot \left(B_i - B_0\right) \cdot \left(B_j - B_0\right)\right) \right| \cdot p\left(B_i\right) \cdot p\left(B_j\right) dB_i dB_j\,. \tag{27}$$

Also, in [9], the definition of the averaged contrast of complex image on the basis of (16) using (25) was proposed:

$$\widetilde{C}_{ave}^{abs} = \int_0^1 \int_0^1 \left|B_i - B_j\right| / \left(B_{\max} - B_{\min}\right) \cdot p\left(B_i\right) \cdot p\left(B_j\right) dB_i dB_j\ . \tag{28}$$

The incomplete integral contrast for kernel of absolute contrast (23), by analogy with (21) and (22), is defined as:

$$C_{ii0}^{abs} = 2\alpha \cdot \left(B_i - B_0\right)/\left(1 + \alpha^2 \cdot \left(B_i - B_0\right)^2\right). \tag{29}$$

$$C_{\Sigma}^{abs} = 2\alpha \int_0^1 \left|B_i - B_0\right| / \left(1 + \alpha^2 \cdot \left(B_i - B_0\right)^2\right) \cdot p\left(B_i\right) dB_i\,. \tag{30}$$

In [6], an assessment of the incomplete integral contrast on the basis of the kernel of absolute contrast (24) was proposed:

$$C_{\Sigma}^{Vrb} = \int_0^1 \left| \left(B - B_0\right)/BMAX + 1/2 - \left|\left(B - B_0\right)/BMAX - 1/2\right| \right| \cdot p(B) dB\,. \tag{31}$$

In [6] the expression (31) was also presented in the form:

$$C_{\Sigma}^{Vrb} = \int_0^1 \min\left(2\left|B - B_0\right|/BMAX, 1\right) \cdot p(B) dB\,. \tag{32}$$

The choice of value B_0 of adaptation level appreciably defines the effectiveness of assessment of the generalized contrast of multi-element images.

The B_0 value of the adaptation level is most often taken to be equal the average value of the brightness of the current image, B_0 = mean (B) (9) [5, 6]. In [6], the brightness value in the midpoint of the brightness range of the current image was proposed as the value of the adaptation level:

$$B_0 = (B_{\min} + B_{\max})/2. \tag{33}$$

In [10], as the adaptation level, it is proposed to use a brightness value at which the estimation of the generalized contrast of the current image takes a minimum value.

Definitions (17), (27) and (22), (30), (31) are no-reference metrics for measuring generalized and incomplete integral contrast using the known weighted and absolute contrast kernels. However, it should be noted that the known definitions of generalized and incomplete integral contrast have several significant shortcomings, which significantly reduce the effectiveness of their practical use [9].

Their main shortcoming is the discrepancy with the basic requirements (2)-(4) to the definition the contrast of the image [6, 7]. The contrast C_{ij0} of the elementary two-element image relative to the preset adaptation level B_0 is a symmetric function:

$$C_{ij0} = (C_{i0} + C_{j0})/(1 + C_{i0} \cdot C_{j0}) = C_{ji0}, \tag{34}$$

and the condition (2) is not satisfied:

$$C_{ij0} \neq -C_{ji0}. \tag{35}$$

The requirements (3) to the definiteness and uniqueness of the conditions for the equality of zero are also not satisfied:

$$C_{ii0} = 2C_{i0}/(1 + C_{i0}^2) \neq 0, \ if \ C_{i0} \neq 0, \tag{36}$$

$$C_{ij0} = 0 \ \forall C_{i0} \ if \ C_{j0} = -C_{i0}. \tag{37}$$

The definition (10) of contrast C_{ij0} also does not satisfy the requirement (4) of the definiteness and unambiguous of the conditions under which the absolute value of the contrast C_{ij0} reaches its maximum:

$$C_{ij0} = -1 \quad \forall C_{i0}, C_{j0} \ \ if \ C_{i0} = -1 \vee if \ C_{j0} = -1. \tag{38}$$

These considered shortcomings (34)-(38) of the known contrast definitions (10), (13), (20) and (21) substantially limit their practical use for assessing the contrast of complex multi-element images.

To address these shortcomings, a new method of measuring the contrast of an elementary two-element image relative to a preset adaptation level is proposed, which satisfies the basic requirements (1)-(5) to the contrast definition. Also new definitions of the weighted and absolute contrast of the image elements are proposed, that satisfy the requirements (1)-(5), and the definitions of generalized and incomplete integral contrast on their basis are considered.

4. The proposed method

In this paper, we propose a new method for measuring the contrast of two elements of a complex multi-element image based on assessments of their contrast relative to a preset value of the adaptation level.

Taking into account the sequence and direction of the transitions $B_i \rightarrow B_0$ and $B_0 \rightarrow B_j$ in the measurements, we propose the new definition for contrast of two element of complex multi-element image with the preset adaptation level:

$$\tilde{C}_{ij0} = (C_{i0} + C_{0j})/(1 + C_{i0} \cdot C_{0j}). \tag{39}$$

where $\tilde{C}_{ij0}$ – the proposed description of the contrast of two elements in image with the preset adaptation level B_0.

Since the contrast is an asymmetric function and in accordance with (2) C_{0j} = - C_{j0}, we propose description the expression (39) in the form:

$$\tilde{C}_{ij0} = (C_{i0} - C_{j0})/(1 - C_{i0} \cdot C_{j0}). \tag{40}$$

The expression (40) describes the proposed method for measuring the contrast of two elements of a complex multi-element image with a preset adaptation level and can be used to measure the contrast of an elementary two-element image.

In (40) the contrast C_{i0} of the two elements was defined in a generalized form. To demonstrate the proposed method the most well-known definitions of the weighted (12) and absolute (23) contrast kernels were used. The weighted contrast of two image elements in accordance with (40) for the kernel of weighted contrast (12) is defined as:

$$\tilde{C}_{ij0}^{wei} = \left(C_{i0}^{wei} - C_{j0}^{wei}\right)/\left(1 - C_{i0}^{wei} \cdot C_{j0}^{wei}\right) = \left(B_i - B_j\right)/\left(B_i + B_j\right), \quad (41)$$

where $\tilde{C}_{ij0}^{wei}$ – contrast of two image elements with the preset adaptation level for weighted contrast.

It should be noted that the value of the weighted contrast (41) does not depend on the adaptation level and corresponds to the most known definition (12) of the weighted contrast of the image elements, $\tilde{C}_{ij0}^{wei} = C_{ij}^{wei}$. For the weighted contrast (41) using (16) we obtain:

$$\tilde{C}_{gen}^{wei} = \int_0^1 \int_0^1 \left|B_i - B_j\right| / \left(B_i + B_j\right) p\left(B_i\right) p\left(B_j\right) dB_i dB_j , \quad (42)$$

$$C_{i0}^{wei} = \left(B_i - B_0\right)/\left(B_i + B_0\right), \quad (43)$$

$$\tilde{C}_{\Sigma}^{wei} = \int_0^1 \left|B_i - B_0\right| / \left(B_i + B_0\right) p\left(B_i\right) dB_i . \quad (44)$$

The absolute contrast of two image elements in accordance with (40) for the kernel of absolute contrast (23) is defined as:

$$\tilde{C}_{ij0}^{abs} = \alpha \cdot \left(B_i - B_j\right)/\left(1 - \alpha^2 \cdot \left(B_i - B_0\right) \cdot \left(B_j - B_0\right)\right). \quad (45)$$

For the absolute contrast (45) using (16) we obtain:

$$\tilde{C}_{gen}^{abs} = \int_0^1 \int_0^1 \left|\alpha \cdot \left(B_i - B_j\right)/\left(1 - \alpha^2 \cdot \left(B_i - B_0\right) \cdot \left(B_j - B_0\right)\right)\right| \cdot p\left(B_i\right) \cdot p\left(B_j\right) dB_i dB_j , \quad (46)$$

$$\tilde{C}_{\Sigma}^{abs} = \alpha \int_0^1 \left|B_i - B_0\right| p\left(B_i\right) dB_i . \quad (47)$$

Expressions (42), (44) and (46), (47) define the proposed definitions of generalized and incomplete integral contrast for weighted (12) and absolute (23) contrast kernels on the basis of the proposed method (40) for contrast measurement.

5. Research

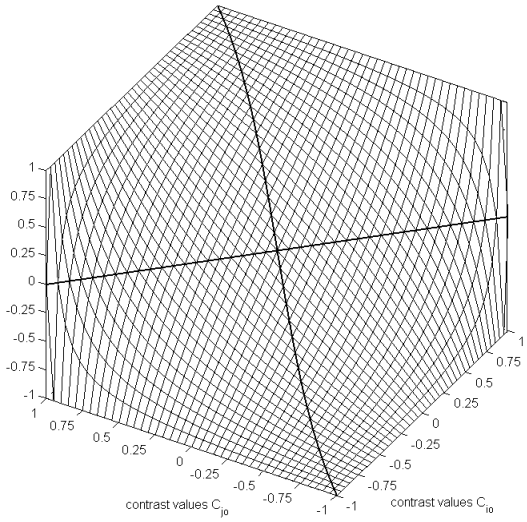
The research was carried out by a comparative analysis of known and proposed definitions of generalized and incomplete integral contrast using weighted and absolute contrast kernels on compliance with the basic requirements (1)-(5) to contrast definition.

3D surface graphs for the known (10), (13) and proposed (26), (40), (41), (45) definitions of contrast are shown in Fig. 1–6.

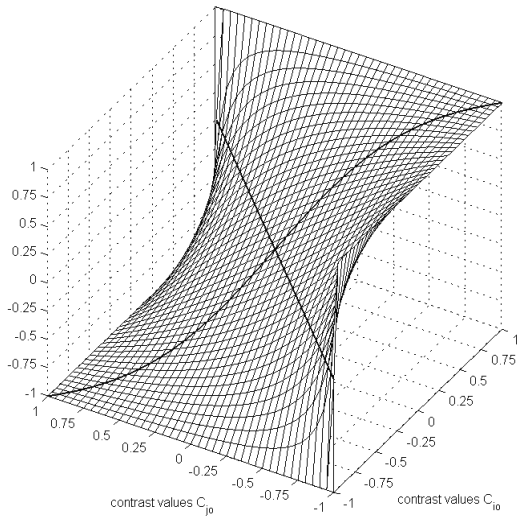
A comparison of known and proposed definitions of contrast was carried out on the basis of measurement of generalized and incomplete integral contrast for a group of nine test images with complex structure (Fig. 7).

The results of the measurement of incomplete integral and generalized contrast for test images are shown in Table 1. The results of contrast measurements for the test images are also shown in the form of graphs in Fig. 8 and Fig. 9.

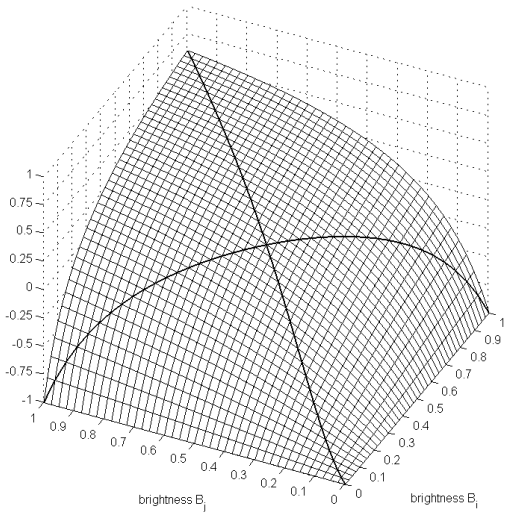
The measurement results using the kernel of weighted contrast (12) for (17), (22), (42) and (44) are shown in Fig. 8.The measurement results using the kernel of absolute contrast (23) for (27), (30), (31), (46), (47) and (28) are shown in Fig. 9.



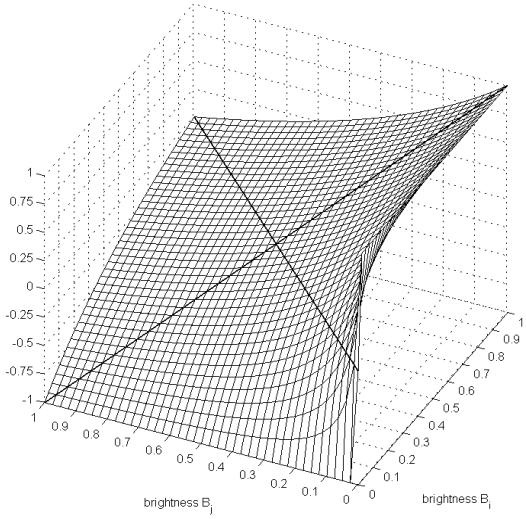
C_{ij0} (10), $B_0 = 0,5$



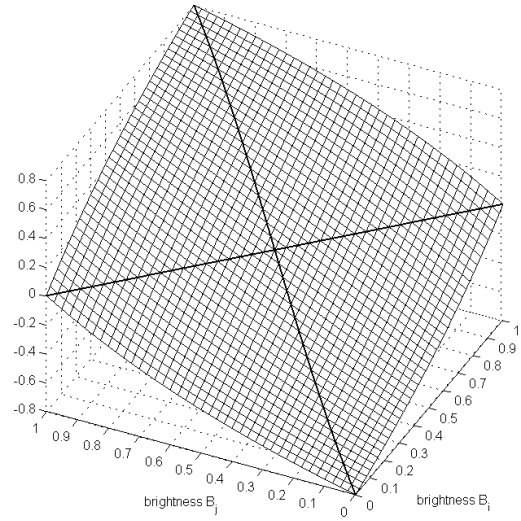
$\tilde{C}_{ij0}$ (40), $B_0 = 0,5$



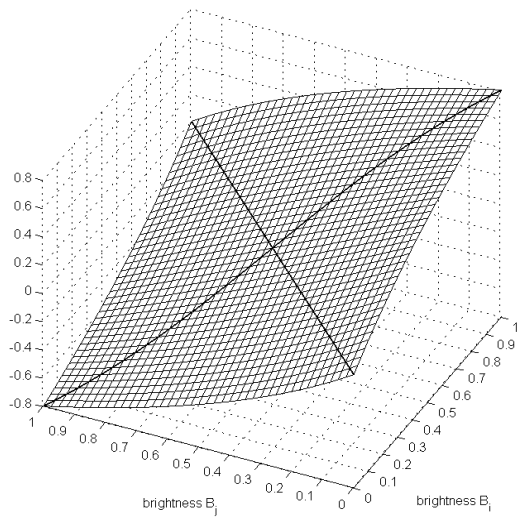
C_{ij0}^{wei} (13), $B_0 = 0,5$



$\tilde{C}_{ij0}^{wei}$ (41), C_{ij}^{wei} (12)



C_{ij0}^{abs} (26), α=1.0, $B_0 = 0,5$



$\tilde{C}_{ij0}^{abs}$ (45), α=1.0, $B_0 = 0,5$

a b d

e f g

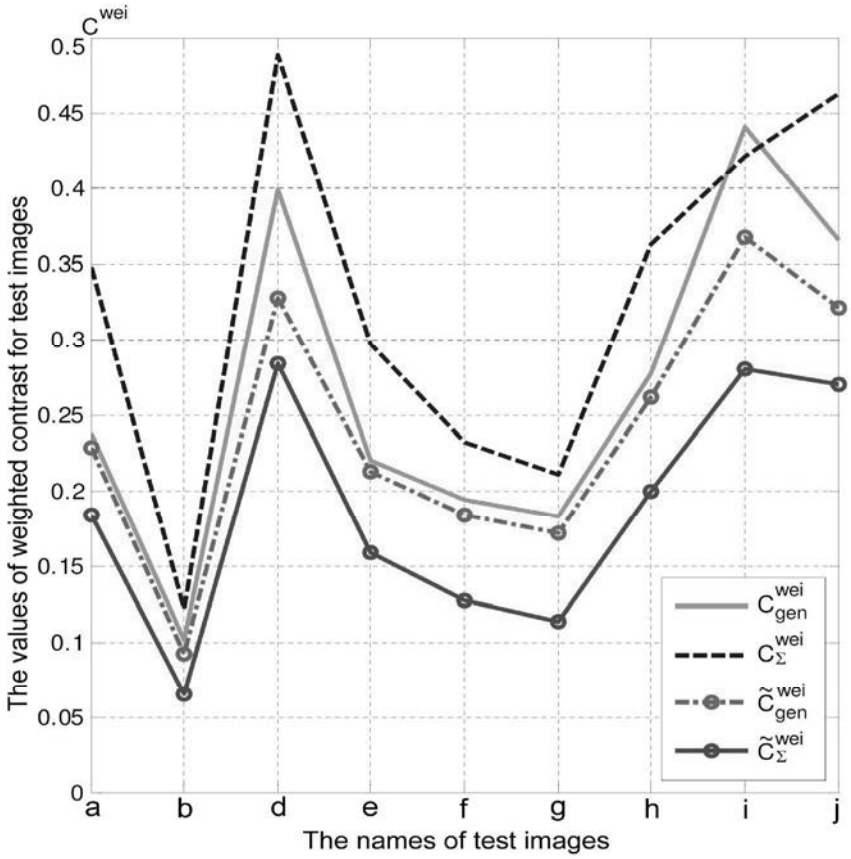
h i j

The appearance of test images

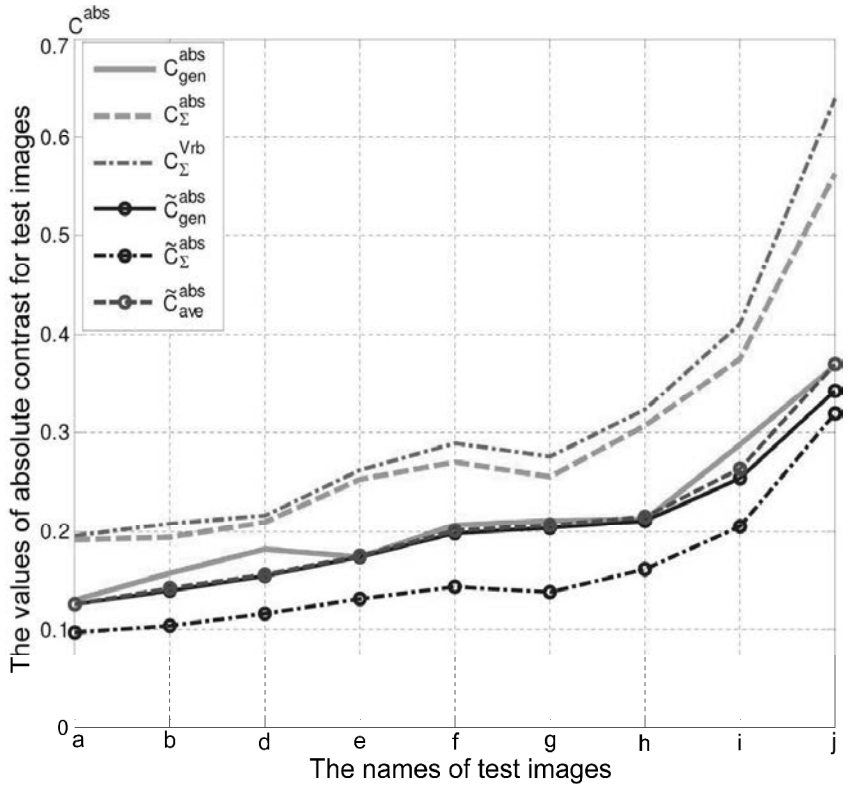
The results of the measurement of incomplete integral and generalized contrast for test images are shown in Table.

The results of the measurement of incomplete integral and generalized Contrast for test images

	C_{gen}^{wei}	C_{Σ}^{wei}	C_{gen}^{abs}	C_{Σ}^{abs}	C_{Σ}^{Vrb}	$\tilde{C}_{gen}^{wei}$	$\tilde{C}_{\Sigma}^{wei}$	$\tilde{C}_{gen}^{abs}$	$\tilde{C}_{\Sigma}^{abs}$	$\tilde{C}_{ave}^{abs}$
a	0.238	0.348	0.130	0.192	0.196	0.229	0.184	0.126	0.098	0.126
b	0.102	0.122	0.157	0.194	0.208	0.092	0.065	0.140	0.104	0.142
d	0.399	0.488	0.182	0.209	0.216	0.328	0.284	0.154	0.116	0.156
e	0.220	0.297	0.173	0.253	0.262	0.213	0.159	0.173	0.131	0.175
f	0.194	0.232	0.207	0.271	0.289	0.184	0.128	0.198	0.144	0.201
g	0.183	0.211	0.210	0.256	0.276	0.172	0.114	0.203	0.138	0.206
h	0.278	0.363	0.212	0.307	0.323	0.262	0.200	0.210	0.162	0.215
i	0.441	0.422	0.288	0.375	0.410	0.368	0.281	0.254	0.205	0.263
j	0.366	0.463	0.368	0.563	0.640	0.321	0.270	0.342	0.320	0.370



The results of measurement of generalized and incomplete integral contrast using weighted contrast for (17), (22), (42) and (44)



The results of measurement of generalized and incomplete integral contrast using absolute contrast for (27), (30), (31), (46), (47), (28)

Analysis of results of the research is carried out in Section 6.

6. Discussion

Analysis of the results of the research shows that all known and proposed definitions (10)-(13), (23)-(26), (29), (45), (47) of the contrast of image elements satisfy the requirements (1) and (5).

However, the known definition (10) of the contrast of an elementary two-element image with a preset adaptation level does not satisfy the main requirements (2)–(4) for the definition of contrast (see (34)–(38) and Fig. 1).

For this reason, the known definitions of weighted (13) and absolute (26) contrast based on (10) also do not satisfy the requirements (2)-(4) and (2)-(3) (see Fig. 3 and Fig. 5), which significantly reduces the accuracy of estimating generalized and incomplete integral contrast using known definitions (17), (27), (22), (30).

The proposed definition (40) (Fig. 2) of the contrast of two elements of a complex multi-element image with a preset adaptation level satisfies basic requirements (1)-(3) and (5) to the contrast definition, but does not satisfy the requirement (4):

$$\tilde{C}_{ij0} = 1 \ \forall C_{j0} \ if \ C_{i0} = 1 \ \vee \ \forall C_{i0} \ if \ C_{j0} = -1. \tag{48}$$

$$\tilde{C}_{ij0} = -1 \ \forall C_{j0} \ if \ C_{i0} = -1 \ \vee \ \forall C_{i0} \ if \ C_{j0} = 1. \tag{49}$$

The contrast definition (41) based on the proposed contrast definition (40) with using the kernel of weighted contrast coincides with the widely known definition (12) of the weighted contrast of image elements and its value does not depend on the level of adaptation.

A main shortcoming of the known definition (12) of weighted contrast is the uncertainty and multiplicity of conditions under which the contrast accepts extreme absolute values (4) (Fig. 4):

$$C_{ij}^{wei} = 1 \ \forall B_i > 0 \ \ if \ B_j = 0 \quad and \quad C_{ij}^{wei} = -1 \ \forall B_j > 0 \ \ if \ B_i = 0. \tag{50}$$

The proposed definition (45) of absolute contrast on the basis of (40) using (23) satisfies all basic requirements (1)-(5) to the contrast definition (Fig. 6).

The results of the research also show that the values of assessments of the generalized (17), (42) and incomplete integral contrast (22), (44) on the basis of the kernel of weighted contrast (12) depend substantially on the average brightness value of the current image (Fig. 8).

It should also be noted that assessments of contrast of complex images on the basis of known definitions (22) and (31) of incomplete integral contrast (19) are significantly overstated [5] (Fig. 8 and Fig. 9). The known definition (28) [9] and the proposed definition (46) on the basis of the propose method (40) using kernel of absolute contrast (23) have the closest values (Fig. 9) and are most suitable for quantitative assessment of generalized contrast of multi-element images with complex structure.

7. Conclusion

In this paper, the problem of increasing the accuracy of measuring the generalized contrast of complex monochrome images was considered.

The new method of measuring the contrast of two image elements for a preset adaptation level for various definitions of the contrast kernel was proposed. The proposed method of measuring meets the basic requirements to the definition of the contrast of image elements.

New definitions of the weighted and absolute contrast of the image elements were proposed, which satisfy the basic requirements to the contrast definition. New definitions of generalized contrast and incomplete integral contrast of a monochrome image for weighted and absolute contrast were also proposed.

The proposed definitions increase the accuracy of measuring the generalized contrast for multi-element monochrome images with a complex structure.

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