Contrast and Contrast Enhancement (in Logic of Visual Perception of Graphic Information)

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***Abstract* – The concept of graphic contrast and issues of digital images' contrast control are considered from the viewpoint of visual perception of graphic information. Roles of color and contrast as its carriers are compared. The priority of the second attribute is shown. However, while color is always visible by definition, contrast can be latent. Contrast enhancement is studied in the context of detection of latent information. Being caused by perception of compared colors, informative contrast is predetermined in terms of hue-saturation-brightness. For the purposes of contrast enhancement the color model HSY is entered into consideration, where the choice of hue and saturation from color model HSB/HSV; of brightness – from color model XYZ is substantiated. Each visual contrast is defined through appropriate material contrast and its visibility functions. The structure of total contrast is resulted. Minding the outlined structure, ways to control contrast are scheduled. Special cases of its realization, when total contrast degenerates to contrasts of hues, saturations or brightness, are analyzed. Algorithms, constructed according to the optically-based theoretical formulae, are tested in natural experiment with reference to each partial contrast. Along with the initial image, the results of its informative processing are presented at magnification of contrast-enhancing factor, demonstrating the transition from zero total contrast (required image fragment is latent) up to its 100% (required fragment is visible). The relation of visibility thresholds of hue-contrast, saturation-contrast and brightness-contrast for the actualized image is estimated. The purport of estimation reflects the fact that chromatic contrast enhancement can be more effective than brightness one. Moreover, be brightness (of required fragment) and brightness (of background) equal, then it would be problematic for regular contrast-enhancing toolkit of modern graphic software to reveal the latent information. While the announced tool ensures successful contrast enhancement. The new approach actually triples volume of the accessible information, received by means of contrast enhancement from the same initial image.**

***Keywords* – graphic information, contrast phenomenon, optical basis, hue-contrast, saturation-contrast, brightness-contrast, contrast enhancement software.**

Conceptually all the efforts of computer graphics are aimed to carry out only two tasks – to synthesize and to analyze images [1] (hereinafter digital images). In this article one of the most relevant computer graphics' regular procedures – contrast enhancement – will be considered only in its second hypostasis – for image analysis.

Introductory Chapters 1 and 2 study contrast phenomenon as an issue of graphic information. Optical aspects of contrast are specified in theoretical chapter III. Technological chapter IV is devoted to the analytical applications of created virtual-optic software product. So this paper is constructed on a border adjoining Optics and Computer Science.

Manuscript received March 19, 2022.

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I. Introduction

Vision and image matters are initially concerned with optics, but not only they: in the current report another optical category is accentuated – information derived from the image. "Thus light, or rather optics, provide us with a very valuable source of information, the application of which can range from very abstract artistic interpretations to very efficient scientific usages" [2]. The prevailing interest represents methods and tools of such derivation.

Pointing out first, that about 90% of information humans acquire visually, this article solely deals with the graphic contrast image attribute. Or not acquire, – in this case concept of latent graphic information comes into consideration. The only way for visual acquisition of latent graphic information is contrast enhancement of faulty images. Occasionally such (information-aiming) applications of contrast enhancement occurred from the very beginning of instrumental photography; expediently – settled within the strict sphere of expert activities [3]. Let us consider informative properties of image attributes from the point of view of graphic information visual perception as applied to the contrast enhancement process. It's appropriate to start with differentiation of color and contrast roles in perception of graphic information.

Main image attributes – color and contrast – carry two types of graphic information: about color and form (shape) of represented subject. Since Maxwell [4] the essence of color itself is obvious, and nowadays color graphic information is contained directly by three RGB-coordinates of digital image pixel. The issue of shape information has appeared less transparent. Maxwell has defined only the colors' distinction, as a predictor of form [5]. And even a century later Hubel speaks about it laconically "Thus color, like black and white, is just one means by which shapes manifest themselves" [6], though this verbally expressed consideration is supported by the amassed graphic constructions in image domain [7]. Let us expand the cited thesis of Nobel laureate.

Shape directly bears the graphic information. To start perception of the shape [8] it is to be initial the visual sensation of contour – the line of visible boundary separating an informative image fragment from others, at present not actual. This boundary is being generated by contrast of adjoining fragments' colors. So, the logic chain turns out, unambiguously connecting shape graphic information with contrast phenomenon, id est the amount of received information is governed by the image contrast. But though means of carrying shape is contrast, color implicitly participates in transfer of non-color graphic information too. In digital image shape information is contained both by two triplets of color coordinates for each pair of neighbouring pixels and by two their spatial coordinates, saved in pixel data indirectly. Besides, color is the carrier of color graphic information itself. Next it will be not unreasonable to compare the potential volumes of color and shape information.

Color information rare happens to be relevant within analytic applications of computer graphics due to restrictions imposed by features of human color perception. Person's eye perfectly feels colors, but his brain badly remembers them. There is nothing to identify current sensations with. But the graphic information comes to light only during mental collation of what is seen now with what was remembered before. That is why color bears practically only the alarm graphic information in outside of significant volumes. Therefore it is true to estimate the color graphic information percentage as negligible.

On the contrary, the shape graphic information prevails over the color one. In the analytical tasks shape is claimed everywhere. In favour of so categorical statement witnesses certain materials obtained from visual perception psychology: "By itself, shape is a better means of identification than color not only because it offers many more kinds of qualitative difference, but also because the distinctive characteristics of shape are much more resistant to environmental variations" [9]. Humans can identify much more shapes, than colors.

Let us review the content of last citation by means of mental model. Looking at the color of yellowed tree crown, it is possible to draw absolutely different conclusions about the reasons of such coloration. And only having recognized the shape of crown minims the correct one can be chosen: if there are pine-needles, – the tree has dried up; if there are leaves, – autumn has come. Hence it follows the shape information priority in most cases of visual analysis.

Thus, through physicists' physiologists' and psychologists' reasoning it turns possible to enter the subject domain of informational (or intelligent) optics and to outline global aim and global task of current research:

- the informationally-oriented aim supposes the significant increase of image fragments' color differentiation up to the level of their visual perception,
- the optically-oriented task supposes the engineering of conformable means and tools for required contrast enhancement.

II. Phenomenological Background

Graphic contrast phenomenon consists in visual sensation of color distinction between adjacent image areas' pairs. If graphic contrast is called latent, it means pairs' color mismatch is lower than the threshold of human eye contrast sensitivity. In the case of null color variance contrast phenomenon doesn't exist. Its metric is to be discussed in the next section.

Nowadays there is no unified approach to define color distinctions (mismatch or variance), generating contrast effect. The same standard [10] describes contrast both as a ratio and as a difference of compared fragments' color properties. But it is not always admissible to define color mismatch by ratio. To get permission for all cases, values of being compared color characteristics should belong to an absolute scale. Minding color transformation the latter is impossible in some color models. The scale of hues does not have natural zero: no one hue can be greater or lesser than another. Contrary to ratio the difference definition is deprived of this trouble and can be used without limitations.

The unity of contrast sensation does not deny the variety of reasons, contrast phenomenon can be induced by. And these reasons at least three: as color is three-dimensional [11], such is contrast. Thus, it is possible to suppose contrast as a function of any color components' triad. Let us discuss first the simplification of RGB-components, in which values (coordinates) data for each image pixel is kept. Total – full, integral or complete – contrast (if it is visible, it is actually sensed by eyes of the observer) is formed in this case by summation of three components. They are defied as partial contrasts – visual contrast of red components $\rho\cdot\Delta R$, visual contrast of green components $\gamma\cdot\Delta G$ and visual contrast of blue components $\beta\cdot\Delta B$.

Here by Greek ρ, γ, β the visibilities of partial material (in other words, formalized by one or another mathematical description) contrasts ΔR, ΔG, ΔB are denoted. That is, visual (even not eye-visible) contrast differs from contrast, measured physically (id est derived from color coordinates), by a multiplier, named visibility. Visibility is not a constant factor, – it depends on color components in a more complicated manner. Each visibility depends both on those color components, by which its contrast is defined, and on remaining color components of fields' pair being compared.

As a fact, the RGB-components' contrast is being changed seldom, because it is too indirectly related with brightness-contrast. This contrast is the most acceptable for human perception, as the eye has the lowest sensitivity threshold to brightness-contrast. Probably therefore it is the only used (with alternating errors) in modern computer graphics instrumentation. If color components directly reflect perceptual color properties, they are named color characteristics. In contrast enhancement applications the availability of reliable interpretation of contrast effect origins is normally peculiar to color characteristics. So, the color characteristic – brightness – allows to treat the original illumination (light-to-dark effects) of investigated picture, but any RGB-component – does not.

But brightness-contrast enhancement will be hopeless, if both brightness of compared image fragments are equal, and brightness component is absent within total contrast. In this case it is necessary to enhance alternative contrasts. Which particularly, – it is defined by the set of characteristics, completing chosen color model. Components of color model should provide the greatest informative ability of generic contrast even if the human eye sensitivity to certain contrast is slight. Basic research [12], where contrast sensitivity is considered solely with reference to energetics, but not to chromatics of electronic images, also testifies about underestimation of informative ability of such, chromatic, contrasts within existing digital, or virtual-optic, technologies for color images' contrast enhancement.

Unlike RGB-components of color, being sensed by human eye, human brain perceives and operates three differing components – optical characteristics of color: hue-saturation-brightness [13] (each can be defined not in the only way, being incorporated into this or that color model, called perceptual or visual). As a result, the contrast phenomenon is acquired as unitary, – not through the separate components by which color is sensed and perceived. Possible differentiation of acquired contrast occurs on the mental stage of information processing, following its perception. So, identification of visible contrast with prevailing partial one (hue-, saturation- or brightness-type) is being realized. Let us apply these considerations to three limitary contrast appearance cases: first by making equal hues and saturations of compared fields' colors, second – their saturations and brightness, third – their brightness and hues. In appropriate cases total contrast will be solely determined by 1) brightness mismatch; 2) hues mismatch; 3) saturations mismatch.

III. Optical Basis

Traditionally optics always paid more attention to color [14] rather than to contrast phenomena. And only with the beginning of computer graphics, opening the possibility to govern the image contrast [15], this rupture began to shorten. Many color models were established, including the variety of suitable for contrast enhancement ones. Namely, perceptual HSB/HSV, HSI, HSL, … and visual Lab/Lch. It's pertinent to analyze both in order to reveal and estimate practical preference of each model for contrast enhancement.

On the assumption of visual registration the best choice is standard Lab/Lch color model (today even more precise ones are accessible – color appearance models by Nayatani, Hunt, Fairchild, … , but they are formalized mathematically in yet more sophisticated way). Though Lab/Lch seems to be perfect for color simulation, it is much worse applicable to transformation of contrast. It is time to concretize a situation.

Within the contrast enhancement process both forward and reverse tasks are being solved. First – the starting contrast is to be calculated, as a function of assigned colors. Second – the resultant colors are to be found, as a function of required contrast. The initial color information in all graphic files is held by values of RGB-coordinates (several graphic file formats exist using other coordinates, but only as addition to RGB). Thus, if visual color model is chosen to operate in, so the processed Lch color data will be linked to basic RGB-coordinates with notably continuous formulae (even neglecting the bifurcation of attendant algorithm by Pauli extension [16]) twice – on the transition pathway 8/16bitRGB→sRGB→XYZ→Lab→Lch and backwards. Besides, calculations, uneasy themselves, becomes much more complicated by the following factor. Color gamut of RGB is narrower, than of Lch [17]. It leads to additional brightness and saturation values calculations, limiting the possibility of contrast conversion of color for each pixel by the RGB range borders. Hence, inadequate machine resources may be required to use Lab/Lch.

In color models, both visual and perceptual, hues differ from other colors by one feature, combining utmost brightness with utmost saturation. But in perceptual ones the RGB-coordinates of each hue (bold-marked) can be revealed via forward computing the next equations:

$$\begin{cases} \mathbf{Min(RGB)} = \mathrm{MinMin}(RGB) \\ \mathbf{Med(RGB)} = \mathrm{MaxMax}(RGB)\dfrac{[\mathrm{Med}(RGB) - \mathrm{Min}(RGB)]}{[\mathrm{Max}(RGB) - \mathrm{Min}(RGB)]} \\ \mathbf{Max(RGB)} = \mathrm{MaxMax}(RGB), \end{cases} \quad (1)$$

where MinMin(RGB) and MaxMax(RGB) – lower and upper borders of 8/16bitRGB-coordinates range, Min(RGB), Med(RGB) and Max(RGB) – minimal, mediate and maximal coordinates values of initial color. Then follows fast logical rescaling (from linear to circular components' presentation) and shifting. Last – the reverse computing equations, inverse to (1). Hues in all perceptual color models HSB/HSV, HSI, HSL, … are defined identically, but not saturations, – their definitions differs considerably. Let us analyze variant cases, but already omitting Lab/Lch owing to the certain considerations summarized above.

In perceptual color model HSI the saturation, depending upon RGB-coordinate values, is defined by the following expression:

$$S_{\mathrm{HSI}} = 1 - 3\mathrm{Min}(RGB)/[\mathrm{Max}(RGB) + \mathrm{Med}(RGB) + \mathrm{Min}(RGB)].$$

In color model HSL the saturation is defined as follows:

$$S_{\mathrm{HSL}} = [\mathrm{Max}(RGB) - \mathrm{Min}(RGB)]/\{1 - |1 - [\mathrm{Max}(RGB) + \mathrm{Min}(RGB)]|\}.$$

In color model HSB/HSV [18] it is defined the most simple way:

$$S_{\mathrm{HSB/HSV}} = [\mathrm{Max}(RGB) - \mathrm{Min}(RGB)]/\mathrm{Max}(RGB). \quad (2)$$

All reviewed definitions somewhat varies by the length of corresponding formulae (not specified here, are even longer). The latter is the shortest, that is – slightly faster to compute. From this point of view the choice of (2) definition is obvious. It is necessary to clarify only that within all unambiguity of the computational formula two ways are possible to calculate S, placing to (2) either 8/16bitRGB, or sRGB values. Henceforward, being guided by the widespread graphic software [19], we will use 8/16bitRGB.

But the basic problems with contrasts' transfer in all the perceptual models are caused by irrational definitions of color brightness characteristic, and not by color chromaticity ones. In HSB/HSV the role of brightness is carried out by value V=Max(RGB), not taking into account both Med(RGB) and Min(RGB);

in HSL the role of brightness is carried out by lightness L=[Max(RGB)+Min(RGB)]/2, not taking into account Med(RGB);

in HSI the role of brightness is carried out by intensity I=[Max(RGB)+Med(RGB)+Min(RGB)]/3, not taking into account the brightness coefficients' difference. These inadequacies motivates to search for brightness characteristic among other color models. Moreover, there is no ban to combine characteristics from different color models – the main claim they must be independent [11].

Let's make a start from all the same Lab/Lch. In this case L should be calculated from 8/16bitRGB through brightness Y, moreover calculated approximately, because the Judd polynomial [20]

$$Y = 1.2219 \cdot L - 0.23111 \cdot L^2 + \\ + 0.23951 \cdot L^3 - 0.021009 \cdot L^4 + 0.0008404 \cdot L^5$$

has the fifth power of lightness, hence under Abel's theorem [21] it is unsolvable in radicals regarding *L*. But even the approximate calculations' duration will not be much shorter, than at processing chromaticity characteristics. Besides, it is necessary to mind that brightness should be calculated not only for brightness-contrast enhancement, but also while saturation-contrast enhancement – it is obligatory – and while hue-contrast enhancement – optionally. It practically triples the required machine resources.

On the other hand, in XYZ color model brightness *Y*, considering Weber' law [22], is adequate to describe proper visible contrast; is hue-corrected; is standardized at the international level [23], and the expressions, connecting *Y* with *RGB* (and vice versa), are still enough compact:

$$Y = \text{К} \cdot R + \text{З} \cdot G + \text{С} \cdot B, \quad (3)$$

where *R*, *G*, *B* – sRGB-coordinates; brightness coefficients К, З, С are borrowed from IEC standard.

Finally the triad of mutually independent color characteristics *H*, *S* and *Y* turns out, that allows to assemble color model HSY. Such model is not ideal entirely, at least regarding the linearity of hues and saturations perception. But this lack is compensated by following reason: of the required contrast overall, brightness component is visually the most appreciable [12]. So the error caused by identification of observed brightness contrast with visual one should be the least, therefore namely brightness demands the most exact (linear) definition (3). Finally, HSY is optimum by criterion: adequacy of contrast representation versus efficiency of contrast conversion. Now, proceeding from the established set of color components, it becomes possible to generalize theoretical reasoning by structurization of total contrast.

To predict observability of total contrast, it is necessary (but not always enough) to clarify whether its components are visible or latent. Let's analyze them. For certain pair *i* and *j* pixels their partial visual contrasts are noted as:

$$\eta \cdot \Delta H_{ij} = \varphi(H_{ij}) \cdot f(S_{ij}, Y_{ij}) \cdot \Delta H_{ij},$$
$$\sigma \cdot \Delta S_{ij} = \varphi(S_{ij}) \cdot f(Y_{ij}, H_{ij}) \cdot \Delta S_{ij},$$
$$\upsilon \cdot \Delta Y_{ij} = \varphi(Y_{ij}) \cdot f(H_{ij}, S_{ij}) \cdot \Delta Y_{ij},$$

where $\Delta H_{ij}=|H_i-H_j|$, $\Delta S_{ij}=|S_i-S_j|$, $\Delta Y_{ij}=|Y_i-Y_j|$ – partial material contrasts of hues, saturations and brightness of *i* and *j* pixels; η, σ, υ – partial contrasts' visibilities, defined by their visibility functions:

- eponymous $\varphi(H_{ij})$, $\varphi(S_{ij})$, $\varphi(Y_{ij})$;
- heteronymic $f(S_{ij}, Y_{ij})$, $f(Y_{ij}, H_{ij})$, $f(H_{ij}, S_{ij})$.

Replacement of H_{ij}, S_{ij}, Y_{ij} by their averages in eponymous functions calls errors $\pm(\bar{H} - H_{ij})$, $\pm(\bar{S} - S_{ij})$, $\pm(\bar{Y} - Y_{ij})$. But their values are significant only in cases when $|H_i-H_j|$»0, $|S_i-S_j|$»0, $|Y_i-Y_j|$»0. Under these conditions contrast is observable with any visibility functions. Therefore such cases are of no interest in prospects of contrast enhancement. So, replacement is valid.

$$\varphi(H_{ij}) = \varphi(H_i/2 + H_j/2) = \varphi(\bar{H}),$$
$$\varphi(S_{ij}) = \varphi(S_i/2 + S_j/2) = \varphi(\bar{S}),$$
$$\varphi(Y_{ij}) = \varphi(Y_i/2 + Y_j/2) = \varphi(\bar{Y}).$$

Since variables *H*, *S*, *Y* of heteronymic functions are independent, it is possible to decompose the last ones as:

$$f(S_{ij}, Y_{ij}) = f_{\text{H}}(S_i, S_j) \times f_{\text{H}}(Y_i, Y_j),$$
$$f(Y_{ij}, H_{ij}) = f_{\text{S}}(Y_i, Y_j) \times f_{\text{S}}(H_i, H_j),$$
$$f(H_{ij}, S_{ij}) = f_{\text{Y}}(H_i, H_j) \times f_{\text{Y}}(S_i, S_j),$$

then partial visual contrasts will become:

$$\eta \cdot \Delta H_{ij} = \varphi(\bar{H}) \cdot f_{\text{H}}(S_i, S_j) \times f_{\text{H}}(Y_i, Y_j) \cdot \Delta H_{ij},$$

where $f_{\text{H}}(S_i,S_j)$ – hue-contrast visibility function for *i* and *j* pixels depending on their saturations, $f_{\text{H}}(Y_i,Y_j)$ – hue-contrast visibility function for *i* and *j* pixels depending on their brightness;

$$\sigma \cdot \Delta S_{ij} = \varphi(\bar{S}) \cdot f_{\text{S}}(Y_i, Y_j) \times f_{\text{S}}(H_i, H_j) \cdot \Delta S_{ij},$$

where $f_{\text{S}}(Y_i,Y_j)$ – saturation-contrast visibility function for *i* and *j* pixels depending on their brightness, $f_{\text{S}}(H_i,H_j)$ – saturation-contrast visibility function for *i* and *j* pixels depending on their hues;

$$\upsilon \cdot \Delta Y_{ij} = \varphi(\bar{Y}) \cdot f_{\text{Y}}(H_i, H_j) \times f_{\text{Y}}(S_i, S_j) \cdot \Delta Y_{ij},$$

where $f_{\text{Y}}(H_i,H_j)$ – brightness-contrast visibility function for *i* and *j* pixels depending on their hues, $f_{\text{Y}}(S_i,S_j)$ – brightness-contrast visibility function for *i* and *j* pixels depending on their saturations.

It is rightful in visual brightness-contrast function to suppose $f_{\text{Y}}(H_i,H_j)=1$ because brightness *Y* in HSY color model is already corrected by brightness coefficients К, З, С. Having transformed the last formula according to this reduction, it becomes quite possible to produce the following manipulations.

Given: expressions to feature partial visual contrasts

$$\eta \cdot \Delta H_{ij} = \varphi(\bar{H}) \cdot f_{\text{H}}(S_i, S_j) \times f_{\text{H}}(Y_i, Y_j) \cdot \Delta H_{ij},$$
$$\sigma \cdot \Delta S_{ij} = \varphi(\bar{S}) \cdot f_{\text{S}}(Y_i, Y_j) \times f_{\text{S}}(H_i, H_j) \cdot \Delta S_{ij}, \quad (4)$$
$$\upsilon \cdot \Delta Y_{ij} = \varphi(\bar{Y}) \cdot f_{\text{Y}}(S_i, S_j) \cdot \Delta Y_{ij}.$$

Desired: expressions to estimate total contrast.

Let us summarize partial visual contrasts. Within analytical geometry two points in cylindrical coordinate system are spaced from each other by distance *ds*, defined by expression $ds^2=d\rho^2+\rho^2 \cdot d\varphi^2+dz^2$, where ρ – radius, φ – azimuth, *z* – height [24]. It is true to pass from abstract distances to contrasts, which in HSY color model are defined by the same cylindrical coordinates:

$$\Delta C^2 = (\sigma \cdot \Delta S_{ij})^2 + (\bar{S}_{ij})^2 \cdot (\eta \cdot \Delta H_{ij})^2 + (\upsilon \cdot \Delta Y_{ij})^2.$$

Here partial visual contrasts are defined by expressions (4), and for any hue $S_i \equiv S_j \equiv 1$. Hence, the total contrast will be equal:

$$\Delta C = \left\{ \begin{array}{l} [\varphi(\bar{S}) \cdot f_{\mathrm{S}}(Y_i, Y_j) \times f_{\mathrm{S}}(H_i, H_j) \cdot \Delta S_{ij}]^2 + \\ + [\varphi(\bar{H}) \cdot f_{\mathrm{H}}(S_i, S_j) \times f_{\mathrm{H}}(Y_i, Y_j) \cdot \Delta H_{ij}]^2 + \\ + [\varphi(\bar{Y}) \cdot f_{\mathrm{Y}}(S_i, S_j) \cdot \Delta Y_{ij}]^2 \end{array} \right\}^{1/2} . \quad (5)$$

At last, as the contrast enhancement task implies only two resultant possibilities (required contrast either is visible, or not), a right part of (5) can be defined as biased argument of Heaviside step function [25]. Physical treatment of argument is contrast sensitivity of an eye; physical treatment of its bias is threshold of this sensitivity:

$$\Delta C_{bin} = \mathrm{H} \left\{ \sqrt{ \begin{array}{l} [\varphi(\bar{S}) \cdot f_{\mathrm{S}}(Y_i, Y_j) \times f_{\mathrm{S}}(H_i, H_j) \cdot \Delta S_{ij}]^2 + \\ + [\varphi(\bar{H}) \cdot f_{\mathrm{H}}(S_i, S_j) \times f_{\mathrm{H}}(Y_i, Y_j) \cdot \Delta H_{ij}]^2 + \\ + [\varphi(\bar{Y}) \cdot f_{\mathrm{Y}}(S_i, S_j) \cdot \Delta Y_{ij}]^2 \end{array} } \right\} . \quad (6)$$

Thus, total contrast in its binary form (being converted either to 1, or to 0) remains as informative for the purpose of visual investigation, as in (5).

It is logical to generalize the derived formula and its derivation as the theorem about total contrast: «Total contrast of pair *i* and *j* pixels is defined by expression (6)». This theorem allows to reveal metabolism of partial (visual and material) contrasts, resulting either in visible, or in latent total contrast.

Both situations, being united by (6), are obvious. At ΔC_{bin}=1 total contrast is great enough for visual perception. Such a case describes the already sensed reality and any demand for contrast image processing is informationally excessive. The inverse situation is more interesting in applications, when contrast and transferred by it graphic information are real, but not felt by the eye ΔC_{bin}=0. If total contrast lies below the threshold of eye's contrast sensitivity, the increase of visual information is potentially possible.

Conceptually this increase can be realized by variation of this or that visibility function (physiological mechanism of contrast enhancement) and by growing of this or that partial contrast (physical mechanism). Preferential is the last way, the stronger one. Let's analyze (6), varying among themselves three material contrasts:

- in the absence of all partial contrasts (not only this or that material contrast may vanish, but its visibility also) the total contrast ΔC_{bin}=0. It is the evenly painted surface. Any object is absent in such image, and this fact appears to carry the extremely important information, if speaking about expert investigations;
- in the absence of partial saturation- and brightness-contrasts, the total contrast is reduced to visual hue-contrast

$$\Delta C_{bin} = \mathrm{H}\{\varphi(\bar{H}) \cdot f_{\mathrm{H}}(S_i, S_j) \times f_{\mathrm{H}}(Y_i, Y_j) \cdot \Delta H_{ij}\}; \quad (7)$$

- in the absence of partial brightness- and hue-contrasts, the total contrast is reduced to visual saturation-contrast

$$\Delta C_{bin} = \mathrm{H}\{\varphi(\bar{S}) \cdot f_{\mathrm{S}}(Y_i, Y_j) \times f_{\mathrm{S}}(H_i, H_j) \cdot \Delta S_{ij}\}; \quad (8)$$

- in the absence of partial hue- and saturation-contrasts, the total contrast is reduced to visual brightness-contrast

$$\Delta C_{bin} = \mathrm{H}\{\varphi(\bar{Y}) \cdot f_{\mathrm{Y}}(S_i, S_j) \cdot \Delta Y_{ij}\}. \quad (9)$$

If at least one of partial contrasts is not equal to zero, some object in such image takes place. But for small partial contrasts, the total contrast is small too (even with 100% visibility functions) and the object can be imperceptible for an eye. The similar case, when total contrast (6) is equal to zero, demonstrates Figure 1 (upper half) in the next Section. Increasing this or that partial contrast, it is possible to enforce the total contrast to overcome the threshold of human eye' contrast sensitivity – object becomes visible. Cases, when as a result of target amplification of hue-contrast ΔH_{ij} close to (7), of saturation-contrast ΔS_{ij} close to (8) and of brightness-contrast ΔY_{ij} close to (9) total contrast becomes equal 1, are shown on Figure 2, Figure 3 and Figure 4. Completing theoretical manipulations, it is impossible to ignore the relation of total contrast (6) with Color Difference (Color Difference Formulae [26]). Resuming this question briefly, – they are two similar, but not rigidly bound among themselves, characteristics of image fragments' comparison. Matter is to be concretized in the separate article.

IV. Software Realization

Reasoning from the optically-based theoretical grounds, new algorithms for images' informative contrast enhancement have been developed. Under conditions of a priori materials' limitation these algorithms realize methodology of Blind Metric [27], – when the revealed graphic information cannot be visually compared with the initial image. They complement the diversified software for brightness-contrast enhancement [28] by two channels for chromatic-contrasts, what allows to treble possibilities of graphic information detection.

But the principal advantage of novation consists even not in this growing informative ability of contrast-enhancing procedures, but in acquiring the possibility to visualize any latent fragment. When, naturally, such fragment takes place in the investigated image (when at least one of partial physical contrasts is not zero).

To demonstrate such possibilities the image, earlier used in this role, has been chosen. It is identical to already published in [29], [30], [31]. The journal cover of polygraphically-dyed cardboard has served as a ground for creation of initial image. Above by one hand were executed two signatures using a pair writing tools of different color. Both did not differ much from the color of background dye. Nevertheless, one of two signatures has appeared quite visible, but another – latent for human eye. The task is not only to save the visibility of the already perceived signature, not only to reveal the latent one, but also to try to compare the efficacy of hue-contrast, of saturation-contrast and of brightness-contrast enhancement.

The inscribed left top corner of a cover has been scanned in 8bit/channel color with spatial resolution 254 dpi. The digitized image 444×562 pxl was saved in .bmp format. Then by means of Photoshop v. 12.1 its dynamic resolution was driven up to 16bit/channel and file was resaved in .png format. Initial image is shown in Figure 1. The increased size allows to ascertain that one signature is visible only.

Figure 1: Initial image.

Further this image was processed in three ways, aiming to reveal the initially invisible fragments – results are presented in Figure 2, Figure 3, Figure 4. Values M of contrast-enhancing factors are listed under each figure (from left to right).

The first way – hue-contrast enhancement – illustrates Figure 2. Henceforward transformation was carried out in 16bit/channel algorithm version. RGB coordinates of the reference hue – R_0=45055, G_0=65535, B_0=0 – were selected "manually". Similar processes are trivial, therefore are not reflected in the article. Peculiarity of hue-contrast control in this case (due to the hue-to-brightness conversion it is possible not for all initial images) – use of procedure of brightness restoration up to the initial value. Here it was carried out in True Mode with an error less than 0.000005. In the absence of such possibility while complex strengthening of heteronymic contrasts, the hue-contrast enhancement is to be carried out last.

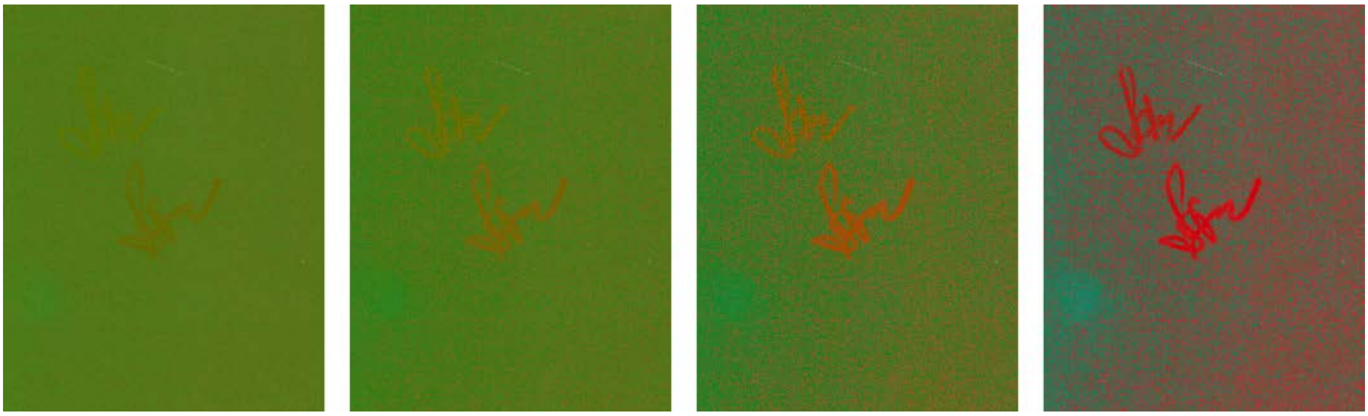

Figure 2: Hue-contrast enhanced images (M=1.05; M=1.15; M=1.35; M=1.75).

Let's compare the resultant images with initial (Figure 1). In the left result the top signature is observable, but it is disputable. In other results two signatures are surely looked through. Therefore it is true to consider that the sensitivity threshold of hue-contrast is demonstrated by the result received at low contrast-enhancing factor M=1.15.

The second way – saturation-contrast enhancement – represents Figure 3. The reference saturation S_0=1. For saturation-contrast control the same peculiarity of processing, that for hues, is characteristic – brightness restoration up to the initial (Figure 1) level. But at saturation-contrast enhancement, unlike hue-contrast, this restoration procedure is applicable to already all the initial images. Here the restoration procedure was used again in the same True Mode and with the same accuracy, as the resultant images, represented in Figure 2, were processed.

Figure 3: Saturation-contrast enhanced images (M=1.25; M=1.75; M=2.75; M=4.75).

Situation in Figure 3 noticeably differs from Figure 2. If in the left result only one signature is visible undoubtedly, in the right – certainly enough two are. To claim that the top signature can be seen even at M=2.75, it is problematic. Consequently, the threshold of visual sensitivity for hue-contrast should be concerned with already greater contrast-enhancing factor M=4.75.

The third way – brightness-contrast enhancement – demonstrates Figure 4. For this case the reference brightness Y_0 was equal 11007 (16bit scale).

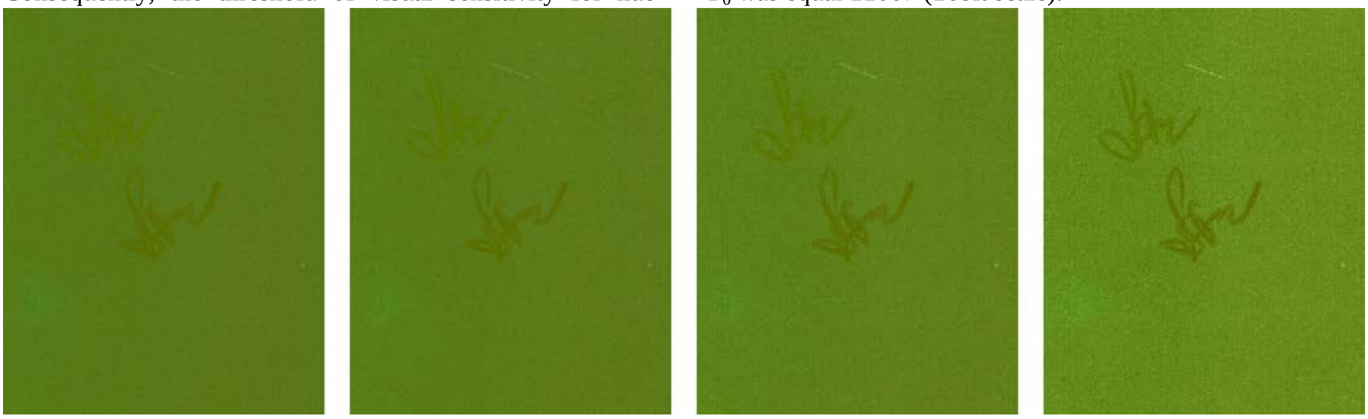

Figure 4: Brightness-contrast enhanced images (M=1.05; M=1.15; M=1.35; M=1.75).

Figure 4 illustrates specific case. At M=1.15 the upper signature is still absolutely invisible, but at M=1.35 – is visible unambiguously. And, so far as the insignificant interval $1.15<M<1.35$ lies between them, it is admissible to define the visual sensitivity threshold of brightness-contrast by its center M=1.25.

Let's discuss results all-together. Firstly, it is possible to state: the positive result of advanced contrast-transforming algorithms' approbation at collating initial and resultant images is obvious. Through all the three proven in theoretical section methods the task for visual differentiation of latent image fragment from its background is being solved. Imperceptible in the initial picture (Figure 1) upper signature as a result of contrast enhancement becomes so clear, that sometimes may be suitable not only for visual identification, but also for machine analysis.

Thus, Figures 1 … 4 demonstrate not only the most urgent for forensic examinations property of contrast-enhancement toolkit to raise images' informative ability, turning a latent image fragment into visible. But besides it – the unique possibility to make visible only one (the required one) of three perceptual contrasts, keeping for the rest two status quo. Last circumstance is informative from the view-point of establishing the nature of contrast-enhanced fragment. At the expense of it the elementary – in arithmetic measure – gain of being revealed graphic information (from initially one signature → to resultant pair of signatures) comes valuable multiply.

Secondly, it's interesting to compare the localization of visibility thresholds for different color characteristics. Let's estimate their disposition by values of contrast-enhancing factor M, required to visualize the upper signature. For Figure 2, Figure 3 and Figure 4 these values considerably differ from each other. While for achievement of visual effect through hue-contrast enhancement it is enough to raise M by 15 % only, using saturation-contrast enhancement it is required to increase M already almost 5 times. But on the way of brightness-contrast enhancement it is necessary to increase M by quarter. As appears from the considered example, the color (by HSY-contrasts) differentiation of latent inscription from background can be multiply more informative, than solely brightness procedures, if compared with illustrated ones in [32]. After all, the image fragments, subjected to contrast enhancement, can be equally bright themselves.

Let's comment on the fact that these data weakly correlate with the ability of human eye to resolve hues, saturations and brightness of color. Moreover, the visibility functions of generic contrasts after processing are close to be optimum. The matter is, that the received ratio for thresholds of contrast-enhancing factors is intrinsic only for this very image. For another object of examination M factors can change radically. Supposing applications within forensic examination, it is appropriate to believe that values of M will be entirely dictated by the initial image. As a result of such conclusion the numerical criterion comes possible to describe the achievement of this or that contrast sensitivity threshold. It means the availability to visual identification of actualized image fragment at the least M. Alike criterion is essential for results' documentation [33] in technological applications of the developed algorithms.

V. Conclusion

Thus, the proposed color model HSY has allowed us to formulate mathematics of contrast enhancing transforms. The last together with appropriate (meanwhile were approved only linear ones) control systems made it possible to elaborate a set of algorithms [29], [30, 33] and [31], whose operation is demonstrated in the present paper. Summarizing the issue, it is possible to ascertain, that the stated task is solved and the desired aim is reached: methods and means to enhance the images' contrast are worked out, results of their application provide the significant increase of images' informative ability. Algorithms guarantee independence of any of HSY-contrasts' transform upon two others. The created product can be useful in the following development of specialized software for forensic applications.

Finally, let us designate the particular directions of further efforts.

In theoretical domain the deep research of partial contrasts' metabolism and its affect on total contrast seems to be the most essential. The structure of visual contrast, set forth in the article, now allows to carry it out, experimentally defining visibility functions of each material contrast.

In applied domain the comprehension of regularities of partial visual contrasts' behaviour attracts by a possibility to predict the total contrast a priori while informational color transform. Such prospect works in favour of not only author's preferences, but also of numerous – from microscopic to airspace – applications of contrast-enhancing instrumentation.

Acknowledgment

Author is indebted to V.A. Chuiko (ITMO University, Saint Petersburg) for numerous critical discussions on the article material.

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