ON PROBLEMS OF COMPARING CARTOGRAPHICAL IMAGE ESTIMATES MADE BY MEANS OF VISUAL IMAGE ANALYSIS AND COMPUTER PROCESSING

Nyrtsova T.P., Strizhkin I.I.

The Moscow State University of Geodesy and Cartography,
#4 Gorokhovsky By-street, Moscow 105064, RUSSIA
e-mail: kartfak@miigaik.ru

Abstract. Results of various analog-digital types of image processing, in particular, on the computer, can be used in addition to visual estimates at some stages of making cartographical products, developing and estimating their design, selecting the optimum option. In this case there arises a problem of comparing data of visual and computer processing of corresponding images, as well as the problem of presenting data of image computer processing in the terms comparable to the data of their psycho-visual estimate.

One of the common properties of images, used both at visual and computer processing of information, is "contrast". A great variety of types of contrasts and their mathematical estimates leads to incorrect applications of this concept to some cases of image processing. The purpose of the paper is to discuss features and opportunities for application of the notion of "contrast" while comparing the results of visual analysis and computer processing of images.

A GENERAL CHARACTERISTIC OF THE CONCEPT OF "CONTRAST". CLASSIFICATION OF CONTRASTS

The concept of contrast is widely used in various fields of activities (psychology, art, cartography, physics, aerial photography and surveying, etc.), and it is frequently used in absolutely different ways. The term "contrast" designates very often – and this meaning is the main one from linguistic point of view – "the maximal difference", "contrast" (from French '*contraste'* which means acutely expressed opposition)" [1]. In psychology "contrast is a subjective exaggeration of distinctions of objects perceived or separate areas of the field of vision in spatial (*simultaneous contrast*) or *temporary* (successive contrast) contiguities in perception" [1]. They usually start talking about contrast when an objective distinction between two images is exaggerated subjectively, for example, black next to white seems to be even blacker. In physics and engineering, this term is rather often used in completely different meanings, for example, in the sense of "the degree of distinction between some object and its background", "contrast sensitivity" is used in the sense of "discriminative sensitivity" and others. In cartographical design, contrast is one of the main means of organizing a logical composition. Contrast can manifest itself in distinction of shapes, forms, sizes, and colors. By developing the color composition of a map it is necessary to take into consideration neighboring colors, the intensity of colors of hypsometric layers, resulting in a sensation of a certain difference in the map user's perception of colors.

There are concepts of *photographic contrast* (a difference of the greatest and the least optical densities), *visual contrast* and others [2]. The examples given show the broad range of use of the said term.

Visual contrast and its features are of interest especially from the point of view of a visual estimate of images. In the field of visual perception, they distinguish the following types of visual contrasts: brightness (light), color value, chromatic (color), simultaneous, successive, boundary, threshold, binocular contrasts. The notions specified are used for quality rating distinctions of visual perception of simple images consisting of two-area object, the term "contrast" being used either in the sense of subjective exaggeration of distinctions, or as a means of estimating sharp difference.

So far, in cartography there has not appeared any uniform procedure for an objective estimate of perception of the information on maps, which is a considerable drawback from the point of view of improving graphic means for conveying the map content. Psycho-physiological laws of visual perception, applied to cartography, including «the law of contrast», help to some extent cartographers develop the best variants of color compositions of maps and atlases; the results of search, however, for the most successful versions of art compositions are generally based on subjective opinions.

A quantitative assessment of distinction of objects perception can be given on the basis of this or that psychophysical law: Weber-Fechner law, Stevens' power law, etc. [3]. In the fields connected with a visual estimate of information, Weber-Fechner law, for example, is used most often in the form of:

$$\Delta S=k\Delta R/R, \quad (1)$$

where ΔS is a minimum gain of sensation relative to the reference level (S is a psychological, subjective quantity), ΔR is a minimum gain of intensity of the irritation necessary for the observer to have got a sense of a minimum perceptible difference (R is a physical quantity, a quantity of irritation, the so-called stimulus), k is a constant of proportionality.

Formula (1) can be used for estimating visual sensations of distinction of perceived objects (contrasts) in objective, physical quantities.
As applied to light sensations it is found out that quantity:

$$K_{th}=\Delta B/B=(B_1-B_2)/B_1 \quad (2)$$

appears practically constant in a wide range of changes of brightness levels and is equal to about 0.02 (here B_1 and B_2 are brightness levels of two neighboring surfaces of sufficiently great angular sizes). Quantity K_{th} is called the threshold of differential sensitivity or the *threshold contrast of brightness levels*. If some surfaces of a considerable difference in area have brightness levels of B_1 and B_2, that is ΔB lays outside the threshold perception, then relation (2) is not valid for them and the relative brightness level of the surfaces is characterized by the contrast of brightness level which is a finite quantity rather than by threshold contrast K_{th}. In particular, the quantity of contrast can be of a maximum: $\Delta B_{max}/B_{max}$. The estimate of such distinction, however, is beyond psychophysical laws.
In various humanitarian and engineering sciences the following formulas are often used for mathematical estimation of contrasts:

$$K=(R_{\mathbf{max}}-R_{\mathbf{min}})/R_{\mathbf{max}};$$
$$K=(R_{\mathbf{max}}-R_{\mathbf{min}})/(R_{\mathbf{max}}+R_{\mathbf{min}}) \quad (3)$$

and others, where R is some physical quantity for which contrast K is calculated. Most of formulas are forms of mathematical estimation of the relative change of some physical quantity R.

Thus, discrepancies in interpretation of the term "contrast" arise already in the field of visual perception of images. On the one hand, distinctions in threshold quantities characterizing images and obeying the laws of psychophysics are called “contrast”. On the other hand, mathematical estimation of images to be compared and their differences (minimum, maximum, relative ones and so on) are also interpreted as contrast. In the first case, the mathematical estimate of contrast is similar to visual sensations. In the second one, only in that specific case of estimating maximum differences of images, the notion of contrast corresponds to that in psychology. Appropriate formulas (3) can be used in that case. As it is known, in visual perception the eye can estimate a relative difference of two quantities (maximum, minimum ones), but cannot give a quantitative assessment of their distinction (by how many times). Due to that, calculation of quantity $(R_{\mathbf{max}} - R_{\mathbf{min}})/2$ and its interpretation as an “averaged contrast” are of a formal nature which is not related to psycho-visual estimation of the image. A failure to take into account this circumstance leads to a formal application of the term "contrast" and does not make it possible to compare properly the data of visual and mathematical processing of images.

FEATURES OF MATHEMATICAL ESTIMATIONS OF CONTRAST OF COMPLEX-STRUCTURED SURFACES AND THEIR INTERPRETATIONS

Let us view features and possibilities of application of the concept of "contrast" to estimating complex (multi-area, interconnected, etc.) images of various structures (textures). There are available natural textures (like fabric, fiber, the surface of sand, of water, etc.), structural textures (these consist of geometrically regular or almost regular repeating figures or patterns) and stochastic textures having a stochastic nature of the pattern of its elements in shape, form and size, as well as their distribution in the area. The content on maps is conveyed by means of lines (hatches) and background, representing various textures: hachure, points, combinations of hachure and points, etc. Mathematical processing of the image of a complex structure often consists in determining its statistics, for example, an averaged value of optical density D, dispersion, correlation function, spectral density and others. We should point out that in literature, for example in [4, 5], (there are few papers on this problem) it is asserted that “the dispersion of a photo image is used to characterize contrast, and the spectral density of the image describes the frequency distribution of contrasts of this image", not a single paper giving any proofs of the said statement. It is not clear what types of contrasts are discussed and whether they are related or not to visual contrasts in any way or whether it is a purely mathematical characteristic of the image that is formally identified with the concept of "contrast".

In our opinion, the interpretation specified of statistics of the image is not correct; the concept of contrast in the sense that is used now with reference to visual contrasts is not valid here. In visual estimation of the image, such quantities like values of averaged optical density D, dispersion D, and others cannot be assessed. Obviously, it is valid in all cases when mathematical estimation of contrast is determined by formulas other than (1) or (3). We can provide a corresponding proof for a case when a site of a homogeneous background and a regular texture is analyzed, for example, a linear raster screened site on a map (Fig. 1).

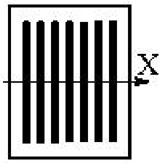

Figure 1

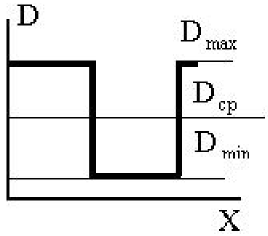

Figure 2

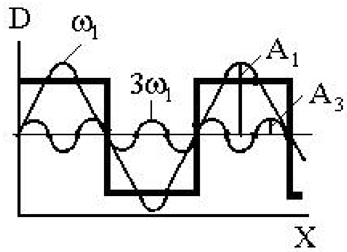

Figure 3

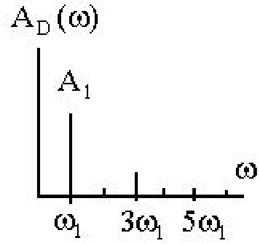

Figure 4

Figure 2 shows a diagram of the change of optical density D along axis x : $D(x)$

As it is known, any periodic function can be expanded into a Fourier series. In this case the spectrum of the assumption function $D(x)$ will be discrete (Fig. 4) and contains odd harmonics: $\omega_1, 3\omega_1, 5\omega_1 ...$ It is clearly seen from an analysis of Fig. 3 (only the first two harmonics are shown here). From comparison of Fig. 2 with Fig. 3 and Fig. 4 it is visible also that the quantity $D_{\max} - D_{\min} = \Delta D$, describing contrast of the original image, is less than the double amplitude $2A_1$ of the first harmonic, i.e. $\Delta D \neq 2A_1$. The other harmonics do not have any sense either in terms of psycho-visual perception of the image.

The similar situation takes place if we have sites with a stochastic texture. In this case, for example, for a section of a two-dimensional field of the image with a length of L it is necessary to find autocorrelation function $R(\tau)$ and then, through the Fourier transform, spectral density function S(ω):

$$R(\tau) = \frac{1}{L}\int_0^L D(x) \cdot D(x+\tau)dx = \frac{1}{2\pi}\int_0^\infty S(\omega)\cos\omega\tau d\omega \quad (4)$$

$$S(\omega) = 2\int_0^\infty R(\tau)\cos\omega\tau d\tau \quad (5)$$

In this case, the complexity of the given mathematical formulas does not allow us to give (as above) illustrative examples to compare the results of mathematical processing with those of "visual contrasts".

S(ω) characterizes the density of continuous – spectrum frequency dispersion distribution of a steady-flow stochastic process. It is convenient for finding out latent periodicities. It is important to notice that spectral density function is often referred to as power spectral density. Such kind of interpretation is used in electrical engineering, the theory of communications and other adjacent sciences. The specified physical sense is caused by the following reasons. Let some initial signal, for example, electric current i (t), take path through a resister of resistance of 1Ω; then $\left[\overline{i(t)}\right]^2$ is the power of the signal in this resister and, hence, spectral density represents the power spectral density in the resister. Unfortunately, the term "power spectral density" is not seldom used in the field of aerial photography, surveying, printing. For example, in a number of papers, their authors describe "the power spectral density of the image contrast" without any corresponding explanations. We know only one paper [6] whose authors doubt the possibility of using the term "power spectral density" in the field of photography as not having any sense.

Thus, in visual estimation of differences of two objects of the image it is expedient to use the term "visual contrast"; its mathematical assessment results from the basic psychophysical law. In cases of mathematical estimation of images or their distinctions, whose algorithms do not coincide with formulas (1) or (3) for calculating "visual contrast", it is necessary to use the term “calculated contrast”, or the corresponding mathematical terminology describing the calculation formula used. It is obvious that the notion “calculated contrast” is rather conditional and it is not related to the term "contrast" in its initial meaning. Its introduction, on the one hand, makes it possible to formulate more precisely the matter that is discussed in the present paper and, on the other hand, to maintain, to some extent, the settled approach to the problem.

References:

1. A Greater Soviet Encyclopedia. - M.: *Sovetskaya Entsiklopediya*, v. 13, p. 67, 1973.
2. A Physical Encyclopedic Dictionary - M.: *Sovetskaya Entsiklopediya*, p. 310, 1983.
3. Psychophysical investigations of perception and memory. - M.: *Nauka*, 1981.
4. L.A. Bogomolov. – Image interpretation. - M.: *Nedra*, 1976.
5. G.A. Sergeyev, D.A. Yanutsh. – Statistical methods for research into natural objects. - L.: *Guidrometeoizdat*, 1973.
6. K. Mease, T. James. – The Theory of the Photographic Process. - L.: *Khimiya*, 1973.

BIOGRAPHY

Tamara P. Nyrtsova was born in 1949. She graduated from the University of Geodesy and Cartography (MIIGAiK) in 1971 with degree of engineer-cartographer. She has PhD in cartography field. She is a Dean of Cartography Faculty, professor.
Her fields of interests: Cartographical design, Technique and technologies of map creations, Multimedia cartographical products, 3D modeling. As a Dean of Cartography faculty, she is teaching students – future experts in Cartography.

Igor I. Strizhkin was born in 1940. He has PhD in technical physics field. He is professor at the Moscow State University of Geodesy and Cartography (MIIGAiK) at Chair of Physics. He have settled special course “Physics in Cartography” which is reading during 10 years on bases of his scientific researches in technical physic, optical processing of images and polygraphy fields. He has involved to development of the equipment, methods of ocean surface remote sensing and imagery processing and data interpretation methods. His today’s interests: psychophysics of reading and processing of images, ocean physic investigations. He has more then 50 published scientific papers and patents in technical physic, air surveying, photogrammetry, ocean physic, and polygraphy.