Search Algorithm and the Distortion Analysis of Fine Details of Real Images

Sai S. V. and Sorokin N. Yu

Institute of Information Technologies, Pacific National University
Tikhookeanskaya str., 136 Khabarovsk, Russia

Abstract. This work describes a search algorithm and a method of the distortions analysis of fine details of real images based on objective criteria.

1 Introduction

Nowadays for the quality analysis of coding and transfer of images various static and dynamic test tables are used. Methods of measurement of the test table signals or subjective estimations allow for estimating distortions that appear during the image compression, for example, under JPEG, JPEG 2000 or MPEG standards.

It is known, that the distortions are essentially shown on fine structures with low contrast during image compression with losses. In test tables such structures include: stroke patterns such as stroke wedges and zoned lattices, groups of parallel strokes, color strokes, thin lines, fine single details, etc. However, as practice shows, contrast of test tables (hence, fine structures) has a high value, which does not allow estimating distortion of details with a low contrast.

For a full rating of coding quality real test photos or video images are used additionally to test tables. The rating of quality of real images is carried out by subjective methods or with the help of root-mean-square deviations.

Until now the most reliable way of image quality estimation is the method of subjective estimation, which allows for estimating serviceability of a vision system on the basis of visual perception of the decoded image. Procedures of subjective estimation demand a great amount of tests and a lot of time. In practice, this method is quite laborious and restricts the control, tuning and optimization of the codec parameters.

The most frequently used the root-mean-square criterion (RMS) for the analysis of static image quality does not always correspond to the subjective estimation of fine details definition since a human vision system processes an image on local characteristic features, rather than averaging it elementwise. In particular, RMS criterion can give "good" quality estimations in vision systems even after elimination of fine details in a low contrast image after the digital compression.

A number of leading companies suggest hardware and software for the objective analysis of dynamic image quality of MPEG standard [1]. Examples are: Tektronix PQA 300 analyzer, Snell & Wilcox Mosalina software, Pixelmetrix DVStation device. Principles of image quality estimation in these devices are different.

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As an example, PQA 300 analyzer measures image quality using the "Just Noticeable Difference – JND" algorithm developed by Sarnoff Corporation. PQA 300 analyzer carries out a series of measurements for each test sequence of images and basing on the JND measurements it forms a common PQR estimation, which is close to subjective estimations. Snell & Wilcox firm offers a PAR method (Picture Appraisal Rating) for the objective analysis of image quality. PAR technology systems control artifacts created by compression under MPEG-2 standard. The Pixelmetrix analyzer estimates a series of images and determines definition and visibility errors of block structure and PSNR in brightness and chromaticity signals.

The review of objective methods of measurements shows that high contrast images are usually used in test tables, while distortions of fine details with low contrast that are mostly common after the digital compression are not taken into account.

It is necessary to note that there exists a lack of practical objective methods of measurement of quality of real images: analyzers state an integrated rating of distortions as a whole and do not allow for estimating authentically distortion of local fine structures of images.

Thus, the problem of finding the objective criteria of the analysis of fine details distortions of images nowadays is considered important.

[5] and [6] describe methods for the definition analysis of fine details of the test table image. In these works mathematical models and definition rating criteria in equal-contrast color space are described, and a synthesis algorithm of test tables for static and dynamic images is proposed.

In the present article the original method of the distortions analysis of fine details of real images by objective criteria is offered.

2 Search Algorithm of Fine Details

Detailed descriptions of the search algorithms of fine details are presented in well known literature, e.g., (Pratt, 2001) and (Gonzalez, Woods, 2002). These overviews show that in most cases the criteria of the fine details recognition do not take into account the threshold values of the visual contrast.

Consider our developed search algorithm of fine details of the image.

In the first stage the image is broken into blocks of size 3×3 pixels.

In the second stage for each pixel of the block a transformation of primary color signals (*RGB*) into equal color space $W^*U^*V^*$ (Wyczecki, 1975) is carried out:

$$W^* = 25 \ Y^{1/3} - 17\,,$$
$$U^* = 13\, W^*(u - u_o)\,,$$
$$V^* = 13\, W^*(v - v_o)\,,$$

where W^* — is the brightness index; U^* and V^* — are the chromaticity indices; u and v are the chromaticity coordinates in Mac-Adam diagram (Mac Adam, 1974); u_o = 0,201 and v_o = 0,307 are the chromaticity coordinates of basic white color.

In the third stage the contrast of the block in the normalized equal color space is calculated:

$$\Delta K = \sqrt{\left(\frac{\Delta W^*}{\Delta W^*_{th}}\right)^2 + \left(\frac{\Delta U^*}{\Delta U^*_{th}}\right)^2 + \left(\frac{\Delta V^*}{\Delta V^*_{th}}\right)^2}\ , \qquad (1)$$

where $\Delta W^* = 3(W^*_{\max} - W^*_{\min})$, $\Delta U^* = 3(U^*_{\max} - U^*_{\min})$ and $\Delta V^* = 3(V^*_{\max} - V^*_{\min})$ are the values of block contrast on brightness and chromaticity indices, determined by the number of the minimum perceptible color difference (MPCD); ΔW^*_{th}, ΔU^*_{th}, ΔV^*_{th} are the thresholds according to brightness and chromaticity indices for fine details.

Threshold values on brightness and chromaticity indices depend on the size of fine details, background color coordinates, time period of object presentation and noise level.

For fine details with sizes not exceeding one pixel the threshold values are obtained experimentally.

In particular (Sai, 2003), for fine details of the test table located on a grey background threshold values are approximately $\Delta W^*_{th} \approx 6$ MPCD and $\Delta U^*_{th} \approx \Delta U^*_{th} \approx 72$ MPCD.

In the fourth stage we exclude from the analysis the blocks with high contrast and those blocks that have invisible (by eye) changes of brightness and chromaticity. Thus, the remaining blocks have contrast that satisfies to the following condition:

$$2 \le \Delta K \le 5\ . \qquad (2)$$

The distinctive feature of the algorithm is that the thresholds of visual perception of fine details contrast of the image depend on the average brightness of the analyzed block. In particular, the contrast change on light blocks of the image will be more visible than on dark ones.

The given condition can be taken into account with the help of adjusting coefficients during the computation of the thresholds. For example, for the brightness threshold:

$$\Delta W^*_{th} = k_{W^*} \cdot \Delta W^*_{th}\ , \qquad (3)$$

where $\Delta k_{W^*} \approx 1$ for the grey blocks ($70 < W^* < 90$), $\Delta k_{W^*} < 1$ for the light blocks ($W^* \ge 90$), and $\Delta k_{W^*} > 1$ for the dark blocks ($W^* \le 70$).

In the fourth stage (using the standard binary masks) the recognition of the block with the following attributes is carried out: a “dot object”, a “thin line”, a “structure fragment”. As a “structure fragment” the “chess field” fragment is selected.

For one block of size 3×3 pixels the quantity of such masks including their inversion will be equal to 12. Some examples of binary masks are shown in Figure 1.

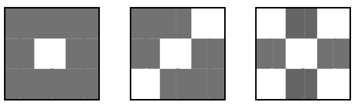

Fig. 1. Examples of binary masks.

For recognition of attributes the image of the block will be transformed to the binary form as follows: for each *i-th* pixel of the block the following condition is checked:

$$\sqrt{\left(\frac{\Delta W_i^*}{\Delta W_{th}^*}\right)^2+\left(\frac{\Delta U_i^*}{\Delta U_{th}^*}\right)^2+\left(\frac{\Delta V_i^*}{\Delta V_{th}^*}\right)^2}<1\,, \tag{4}$$

where $\Delta W_i^* = 3(W_i^* - W_{min}^*)$, $\Delta U_i^* = 3(U_i^* - U_{min}^*)$, $\Delta V_i^* = 3(V_i^* - V_{min}^*)$ are the differences of the coordinates for the comparison of pixel's color coordinates with the minimal value; or $\Delta W_i^* = 3(W_i^* - W_{max}^*)$, $\Delta U_i^* = 3(U_i^* - U_{max}^*)$, $\Delta V_i^* = 3(V_i^* - V_{max}^*)$ are the differences of the coordinates for the comparison of pixel's color coordinates with the maximal value.

If the condition (4) is fulfilled the decision on membership of the pixel to the minimal or to the maximal value is taken. We assign the level of one to the maximal values and level of zero to the minimal values. If the condition (4) is not fulfilled for an *i-th* pixel, this block is excluded from the further analysis.

After that the binary block of the image is compared to the binary image of the *j-th* mask with the help of a simple equation:

$$M_j = \sum_{i=1}^{9}(Ib_i - Mask_{j,i})\,. \tag{5}$$

The decision is made that the given block refers to the image of the *j-th* mask in case if the computed value (5) is equal to zero. The decision about exclusion of the current block from the analysis is made if the value (5) is not equal to zero for all masks.

Thus, the offered search algorithm allows for allocating fine details in the test real image for the further analysis of their reproduction quality in the decoded image.

3 Distortion Analysis

Consider a method of the distortion analysis of fine details of a real image. For the analysis we used two digital images. The first image is in the BMP format and is considered as a reference image received from a scanner or a digital camera. We assume that on the output of the image source the image with a high quality of fine details is formed. The second image (also in the BMP format) is received after processes of compression and decoding of the first image.

In the first stage the search algorithm of fine details of the reference image is carried out.

On the second stage for each found *j-th* block the deviation of the maximal value of color coordinates is computed:

$$\bar{\varepsilon}_j = \max\left(\sqrt{(\overline{W}_i^*)^2 + (\overline{U}_i^*)^2 + (\overline{V}_i^*)^2}\right), \tag{6}$$

where $i = 1 \ldots N$; $N = 9$ is the number of elements in the block and

$$\overline{W}_i^* = 3(W_i^* - \widetilde{W}_i^*) / \Delta W_{th}^*,$$
$$\overline{U}_i^* = 3(U_i^* - \widetilde{U}_i^*) / \Delta U_{th}^*,$$
$$\overline{V}_i^* = 3(V_i^* - \widetilde{V}_i^*) / \Delta V_{th}^*$$

are the normalized to thresholds deviations on brightness and on chromaticity.

In particular if the block is analyzed only on brightness the expression (6) will be transformed into:

$$\overline{\varepsilon}_{j(W)} = \max\left(3\left|W_i^* - \widetilde{W}_i^*\right| / \Delta W_{th}^*\right), \qquad (7)$$

where $\widetilde{W}_i^*$ is the value of brightness of the *i-th* pixel in the image block after the compression.

If the block is analyzed on chromaticity we obtain:

$$\overline{\varepsilon}_{j(U,V)} = \max\left(\sqrt{\left(\overline{U}_i^*\right)^2 + \left(\overline{V}_i^*\right)^2}\right). \qquad (8)$$

Expression (8) determines the maximal error of color transfer of fine details in the block.

Here it is necessary to note that in the compression standards the most complete information on fine details is contained in the brightness component. Therefore, a separate calculation of the errors on brightness and chromaticity is justified.

In the third stage the average values of deviation on brightness and on chromaticity for all image blocks are calculated:

$$\overline{\varepsilon}_W = \sum_{j=0}^{M-1} \overline{\varepsilon}_{j(W^*)}; \quad \overline{\varepsilon}_{U,V} = \sum_{j=0}^{M-1} \overline{\varepsilon}_{j(U^*,V^*)}, \qquad (9)$$

where M is the number of blocks in the image, which contain fine details found by the search algorithm.

In the fourth stage using the error value (9) the quality rating of fine details for transfer and reproduction in the analyzed image is established.

The ten-point scale of quality, used in Adobe Photoshop 5.0 system, during the realization of JPEG compression algorithm is chosen.

Table 1 contains experimental dependencies of the error (9) on brightness from the quality rating R for test images "Lena" and "Barbara". For the analysis the blocks with average brightness in the range ($70 < W^* < 90$) were used.

Table 1. Dependency of the error on the brightness.

R	1	3	5	7	9
“Lena”	1,00	0,80	0,78	0,39	0,16
“Barbara”	0,92	0,72	0,67	0,41	0,21

Figure 2 contains a fragment of the test image "Barbara" (top) and the found blocks with fine details (bottom). On Figure 3 a fragment of the test image with a high quality rating is shown. On Figure 4 a fragment of the test image with a low quality rating after an execution of the JPEG algorithm is shown.

For an illustration of distortions in Figures 3 and 4 the differences of brightness in the blocks of the first and second images are shown (bottom pictures).

Experimental results of research of the error dependences for other test images have shown that for support of a high quality rating ($R > 6$) the average value of the coordinates deviation of fine details on brightness should not exceed 50 % from threshold value: $\bar{\varepsilon}_W \leq 0{,}5$.

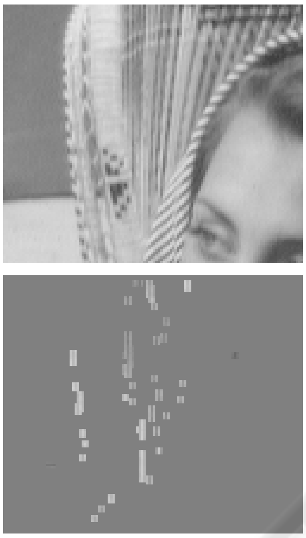

Fig. 2. Fragment of the test image.

Fig. 3. High quality (R = 7).

Fig. 4. Low quality (R = 1).

4 Conclusions

The values of contrast (1) or errors (9) are estimated by a normalized number to visual thresholds. This is an advantage of the developed search algorithm and of the method of the distortion analysis. Therefore, the user can make objective decisions about the presence of fine details in images with a low contrast using expressions (2), (4) and (5) or about the visibility of distortions on values of the error (9).

In conclusion it is necessary to note that the developed search algorithm and the method of the distortion analysis of fine details of real images can be used not only for the error analysis of the JPEG algorithm, but also for any other compression algorithm of static images. In this case, it is enough to compare the received value of the error $\bar{\varepsilon}$ to the quality rating (Table 1).

The method is also applicable for the distortion analysis of fine details of images in the basic I-frames of dynamic video sequences used in the MPEG standards.

The high quality reproduction of fine details of images is an important task for design of vision systems in various applications. The authors hope that the algorithm and the method offered in this work will help designers of vision systems to solve this task more efficiently.

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