Features of the CIE76, CIE-94, and CIE-2000 methods that affect the quality of the determining process of the image average color

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Abstract. Results of pilot studies of the difference in color – the indicator of Delta E determined by CIE-76, CIE-94, CIE-2000 at determination of average color of the digital image are provided. Based on experimental data features of behavior of CIE-76, CIE-94, CIE-2000 calculators on condition of their use for determination of average color of different graphic formats of images were revealed. The research showed that CIE-76 has always the greatest values of the indicator of Delta E. It is revealed at all studied formats of images, irrespective of the prevailing color on the image. In addition, it was established that CIE-94, CIE-2000 show very insignificant deviations from each other and significantly differ from Delta E's indicators of CIE-76 at stages of the maximum reduction of the image. In the analysis of graphic dependences of behavior of the indicator of Delta E it was revealed that CIE-76, CIE-94, CIE-2000 behave probably, saving the main peaks of values. The software in the Python programming language, which showed the efficiency and capability, was developed to measure average color at different images.

1. Introduction
Because of the development of information technologies and improvement of software and hardware tools there are the improvement and emergence of essentially new approaches to different solution of tasks. Having carried out the analysis of the works connected with software processing operations of images it is possible to draw the conclusion that the direction quickly develops, mentions the most different of science and technology. In most cases articles mention problems of pattern recognition, artificial intelligence, determination of zones of risks of constructions, search of images, storage systems of images.

Today the most unexplored problem is the organization of search of images at the request of users and data storage. The matters are still relevant and are many-sided questions. It is possible to carry to similar works.

However, applied sometimes-simple cases which demand search of optimal solutions or development of recommendations for such specialists as 3D-artists, the designer color correctors solving often problems of selection of optimum color of the scene, design, structure of the object it is not enough. Among scientific works as the most related topic, it is possible to call works on optimization of storage of images in databases and optimization of search queries taking into account desirable color of the image [3]. In this article the problem of reduction of records in the database, due to entering of
parameter of the color image was solved. However, it affected optimization of entering of data more in the database as it was offered to enter data not for each record, and to integrate graphics in groups depending on colors. At the same time the H (Hue), S (Saturation) parameters on the basis, which were brought further in the database, were defined.

Therefore we consider that current problems in the field of the analysis and processing of digital images still is the insufficient research of questions of determination of the general color of the image. It affects approaches of selective assessment of zones of the image, and determination of average color, color temperature, image saturation.

The matters for printing industry are not main, but they can significantly facilitate work in the field of multimedia projects, in issues of color correction of art designs, video fragments, and image zones when embedding layers to the final stage. The greatest efficiency this technology can affect problems of preparation of design of products, for example, of primary color of packaging, depending on the color gamma of the label or as the factor influencing lighting of difficult three-dimensional stages. Determination of average color value, can also affect the results connected with CBIR technologies, described in the writings [3], [4] because of estimated bigger accuracy.

At determination of average color, there are many different problems, but main are the speed of the process. As the previous paper [5] showed, the most important condition of reduction of time of determination is the image size, the more pixels it is necessary to poll, and then there is longer the process. To determination of "threshold" behind which the image loses initial average color, it was decided to apply indicator $\Delta E_{ab}^*$, which was defined on the basis of CIE-76 technique. Also, in this work "threshold" $\Delta E_{ab}^* = 2$, as it recommends the CIE-76 calculator was set. The CIE-76 calculator was taken as the basis as it was recommended for determination of the indicator $\Delta E_{ab}^*$ on screens of monitors and other devices.

However, in article [5] the research of behavior of the indicator $\Delta E_{ab}^*$ for other editions of CIE calculators, which can significantly affect expediency of application of the color average method, outputs and the main recommendations from work [5] was not conducted. For elimination of this space, it is necessary to carry out calculations of the indicator $\Delta E_{ab}^*$ for CIE-76, CIE-94, and CIE-2000 calculators.

2. Problem definition

The main objectives, which need to be solved during work, are:

- comparison of behavior of CIE-76, CIE-94, CIE-2000 among themselves in the conditions of reduction of the sizes of original images up to 10% of the original,
- identification of the best graphic image format for this task, correction of «threshold value» $\Delta E_{ab}^*$,
- determination of extent of influence of the prevailing color on the image on «threshold value» $\Delta E_{ab}^*$,
- development of recommendations and software development for determination of average color based on the Python programming language.

3. Theory

The main objective at assessment of average color is comparison of behavior of CIE-76, CIE-94, and CIE-2000 among themselves and refining of «threshold value» after which irreversible color distortion begins.

As control of the deviation of the received average color from reference, original indicator $\Delta E_{ab}^*$, CIE-76, CIE-94 and CIE-2000 determined by techniques was taken. According these techniques, the value $\Delta E_{ab}^* \leq 2$. As the instrument of automation of calculation, third-party calculators were used:

1. Delta-E Calculator (CIE-76) [6].
2. Cie-94 Delta-E Calculator (CIE-94) [7].
3. CIE-2000 Calculator (CIE-2000) [8].

As the main programming language, Python 3 was selected. This choice was caused, and to work as the fact that for Python 3 there are various third-party free libraries, which just allow more effectively with similar tasks. Besides, this language usually provides work without graphic interface, and on
different operating systems. With the current problem definition there is no need to focus on the process speed therefore does not matter what programming language was used. However, it is known that depending on the choice of the programming language and libraries results can differ. Python 3 and PIL library, which was taken as the main during the work with graphics, show the efficiency in the set of projects and to them there are practically no complaints. As for the error of calculations, according to preliminary tests the PIL library yields more exact result, than C# with the built-in methods of poll of channels of pixel color.

4. Results of experiments

Researches were conducted using the developed software based on the Python 3 language and PIL library started on the computer of the following configuration: operating Ubuntu 18.04.2 LTS server system (GNU/Linux 4.15.0-50-generic x86_64); processor: Intel (R) Xeon (R) CPU X5460 @ 3.16GHz; random access memory: 8 GB; system type: 64-bit operating server system.

For the experiment about one sample with dominance of different colors - red, green and blue shades were selected. As formats, bitmap images of the JPG, TIF, PNG, and BMP formats with the resolution of 75 DPI and the geometrical sizes 1024×768 pix were used. Test objects for this experiment are provided in figure 1.

![Figure 1](image URL)

**Figure 1.** Test objects for the experiment for establishment of the threshold of the image size changes without significant distortion of average color

During the experiment, the original file consistently decreased by 10%, up to 10% of the nominal size. Reduction of image sizes was executed by means of the Photoshop program, when saving files the highest quality was selected. All formats remained without application of compression and with the standard Photoshop settings. Change for 10% happened to saving of proportions of drawings, at the same time drawing height changed.

The dimensions and average colors of the image in the RGB model for the red, green, and blue channels are shown in table 4...6 of [5].

Results of experiments, calculations of image average colors and indicator $\Delta E_{ab}$ by techniques of CIE-76, CIE-94, and CIE-2000 are given in table 1…3.

**Table 1.** Comparison of indicators $\Delta E_{ab}$ depending on the graphic format and reduction of the sizes for images there is a lot of red channel

| Percent of reduction, % | $\Delta E_{ab}$ | $\Delta E_{ab}$ | $\Delta E_{ab}$ |
|------------------------|-----------------|-----------------|-----------------|
|                        | CIE-76          | CIE-94          | CIE-2000        |
| 100 (reference)        | 0.00            | 0.00            | 0.00            |
| 90                     | 0.00            | 0.00            | 0.00            |
| 80                     | 0.00            | 0.00            | 0.00            |
| 70                     | 0.2582          | 0.0912          | 0.00            |
| 60                     | 0.2582          | 0.0912          | 0.00            |
| 50                     | 0.2582          | 0.0912          | 0.00            |
| 40                     | 0.2582          | 0.0912          | 0.00            |
Table 2. Comparison of indicators $\Delta E_{ab}^*$ depending on the graphic format and reduction of the sizes for images there is a lot of green channel

| Percent of reduction, % | $\Delta E_{ab}^*$ CIE-76 | $\Delta E_{ab}^*$ CIE-94 | $\Delta E_{ab}^*$ CIE-2000 |
|------------------------|---------------------------|---------------------------|---------------------------|
| BMP format             |                           |                           |                           |
| 100 (reference)        | 0                         | 0                         | 0                         |
| 90                     | 0.2582                    | 0.0912                    | 0                         |
| 80                     | 0.2582                    | 0.0912                    | 0                         |
| 70                     | 0.2582                    | 0.0912                    | 0                         |
| 60                     | 0.2582                    | 0.0912                    | 0                         |
| 50                     | 0.2582                    | 0.0912                    | 0                         |
| 40                     | 0.2582                    | 0.0912                    | 0                         |
| 30                     | 0.2582                    | 0.0912                    | 0                         |
| 20                     | 1.9535                    | 0.6362                    | 0.7102                    |
| 10                     | 1.7225                    | 1.0104                    | 1.0319                    |
| PNG format             |                           |                           |                           |
| 100 (reference)        | 0                         | 0                         | 0                         |
| 90                     | 0                         | 0                         | 0                         |
| 80                     | 0                         | 0                         | 0                         |
| 70                     | 0.5451                    | 0.2808                    | 0.358                     |
| 60                     | 0.5451                    | 0.2808                    | 0.358                     |
| 50                     | 0.5451                    | 0.2808                    | 0.358                     |
| 40                     | 0.5451                    | 0.2808                    | 0.358                     |
| 30                     | 0.5451                    | 0.2808                    | 0.358                     |
| 20                     | 2.2412                    | 1.5815                    | 1.5829                    |
| 10                     |                           |                           |                           |

| TIF format             |                           |                           |                           |
| 100 (reference)        | 0                         | 0                         | 0                         |
| 90                     | 0                         | 0                         | 0                         |
| 80                     | 0.2582                    | 0.0912                    | 0                         |
| 70                     | 0.2582                    | 0.0912                    | 0                         |
| 60                     | 0.2582                    | 0.0912                    | 0                         |
| 50                     | 0.2582                    | 0.0912                    | 0                         |
| 40                     | 0.2582                    | 0.0912                    | 0                         |
| 30                     | 0.2582                    | 0.0912                    | 0                         |
| 20                     | 0.2582                    | 0.0912                    | 0                         |
| 10                     | 2.2412                    | 1.5815                    | 1.5829                    |
Table 3. Comparison of indicators $\Delta E_{ab}^*$ depending on the graphic format and reduction of the sizes for images there is a lot of blue channel

| Percent of reduction, % | $\Delta E_{ab}^*$ BMP CIE-76 | $\Delta E_{ab}^*$ BMP CIE-94 | $\Delta E_{ab}^*$ BMP CIE-2000 |
|------------------------|-------------------------------|-------------------------------|-------------------------------|
| 100 (reference)        | 0                             | 0                             | 0                             |
| 90                     | 0                             | 0                             | 0                             |
| 80                     | 0                             | 0                             | 0                             |
| 70                     | 0                             | 0                             | 0                             |
| 60                     | 0                             | 0                             | 0                             |
| 50                     | 0.5837                        | 0.3349                        | 0.2729                        |
| 40                     | 0.5837                        | 0.3349                        | 0.2729                        |
| 30                     | 0.5837                        | 0.3349                        | 0.2729                        |
| 20                     | 0.9594                        | 0.7319                        | 0.5898                        |
| 10                     | 1.4488                        | 1.0377                        | 0.8068                        |

| Percent of reduction, % | $\Delta E_{ab}^*$ BMP CIE-76 | $\Delta E_{ab}^*$ BMP CIE-94 | $\Delta E_{ab}^*$ BMP CIE-2000 |
|------------------------|-------------------------------|-------------------------------|-------------------------------|
| 100 (reference)        | 0                             | 0                             | 0                             |
| 90                     | 0                             | 0                             | 0                             |
| 80                     | 0                             | 0                             | 0                             |
| 70                     | 0                             | 0                             | 0                             |
| 60                     | 0                             | 0                             | 0                             |
| 50                     | 0.5837                        | 0.3349                        | 0.2729                        |
| 40                     | 0.5837                        | 0.3349                        | 0.2729                        |
| 30                     | 0.5837                        | 0.3349                        | 0.2729                        |
| 20                     | 0.9594                        | 0.7319                        | 0.5898                        |
| 10                     | 1.2747                        | 0.7512                        | 0.8976                        |
Based on experimental results from tables 1…3, graphic dependences of the indicator $\Delta E_{ab}^*$ for the studied formats were constructed. They are provided in figure 2 … 13.

**Figure 2.** Values of $\Delta E_{ab}^*$ for JPG format with the blue color prevailing

**Figure 3.** Values of $\Delta E_{ab}^*$ for the JPG format with the green color prevailing
Figure 4. Values of $\Delta E_{ab}$ for the JPG format with the red color prevailing

Figure 5. Values of $\Delta E_{ab}$ for the PNG format with the blue color prevailing

Figure 6. Values of $\Delta E_{ab}$ for the PNG format with the green color prevailing

Figure 7. Values of $\Delta E_{ab}$ for the PNG format with the red color prevailing

Figure 8. Values of $\Delta E_{ab}$ for the TIFF format with the blue color prevailing

Figure 9. Values of $\Delta E_{ab}$ for the TIF format with the green color prevailing
Figure 10. Values of $\Delta E_{ab}^*$ for the TIF format with the red color prevailing

Figure 11. Values of $\Delta E_{ab}^*$ for the BMP format with the blue color prevailing

Figure 12. Values of $\Delta E_{ab}^*$ for the BMP format with the green color prevailing

Figure 13. Values of $\Delta E_{ab}^*$ for the BMP format with the red color prevailing

5. Discussion of results

The analysis of graphic dependences and tabular data solved the following problems:
1. Reveal the most resistant format to size variation;
2. Set behavior, differences and the possibility of application of different standards according to the estimates of indicator $\Delta E_{ab}^*$;
3. Define whether there is the pattern in behavior of the indicator $\Delta E_{ab}^*$, depending on the prevailing color on the image.

The main task of the research is to increase the speed of process of determination of average color. As we understand now, the most important factor affecting this is the image size. In addition, for this reason, the major task will be to set the most resistant format, which can save at the maximum reduction of image size rather permanent indicator $\Delta E_{ab}^*$.

To solve this problem, we need to add an upper boundary condition as a criterion, under which we are not satisfied with the result. On different sources, it is considered that indicator $\Delta E_{ab}^*$ can vary, but $\Delta E_{ab}^* \leq 2$. However, these recommendations are expected more rough calculation as at the same time use of physical color measurements on the final printing product is provided.

The analysis of graphical dependencies in Figure 2...13 shows that the overall picture is very chaotic. It is possible to set only some explicit and stable parameters. These parameters include:
1. The technique of CIE-76 has always the biggest indicators $\Delta E_{ab}^*$. It is revealed at all formats, irrespective of primary color on the image.

2. All other techniques of calculation of the indicator $\Delta E_{ab}^*$, show very insignificant deviations from each other and the essential difference from CIE-76 indicators at stages of the maximum reduction of the image.

3. At all graphic formats it is possible to select, so-called stable sections. In spite of the fact that, transition to them can be sharp, on these segments, there are no jumps; indicator $\Delta E_{ab}^*$ proves to be steadily.

4. All curves show rather identical trend in the graphs. At insignificant reduction of the image indicator $\Delta E_{ab}^*$ does not change; it is the most favorable zone. Then there is rather long zone of stable and low values of the indicator $\Delta E_{ab}^*$. Then its sharp jump follows.

5. Techniques of CIE-76, CIE-94, CIE-2000 in general behave probably, saving the main peaks of the indicator $\Delta E_{ab}^*$. The main deviations begin approximately at 70% reduction of the image. However, from this point, values of the indicator $\Delta E_{ab}^*$ by CIE-76 technique just sharply increase, and by techniques of CIE-94, CIE-2000 behave more smoothly.

6. Techniques of CIE-94, CIE-2000 relatively each other behave very similarly and almost do not differ neither in dynamics, nor on amplitude of change of values of the indicator $\Delta E_{ab}^*$.

At the stage it is necessary to be defined what method of calculation of the indicator $\Delta E_{ab}^*$ to take as the basis for the further analysis.

We believe that it shall be CIE-76 technique as in case of identification of the exceeding value of the indicator $\Delta E_{ab}^*$, it is possible to tell with confidence that other techniques in this point authentically do not exceed the threshold.

Then it is necessary to reveal formats which exceed the general recommended indicator’s threshold $\Delta E_{ab}^* \leq 2$.

At this stage it is possible to exclude formats of images:
1. JPG (pictures with blue, red colors);
2. PNG (the picture with blue color);
3. TIF (the picture with red color).

The BMP format did not exceed threshold value of the indicator $\Delta E_{ab}^* \leq 2$ anywhere. Therefore, this format can be considered actually the first in firmness for the problem of determination of average color of the image. It is confirmed in our previous paper [5].

After the answer to the matter to analyze reasonably this graphic format on change dynamics of the indicator $\Delta E_{ab}^*$, and to set «safe» zones of its change. We will consider those sections, after which the sharp jump or chaotic dynamics of change indicator begins.

It is necessary to consider that in our case the image has the most exact indicators of color in each pixel and it is necessary much more strict to approach us the choice of admissible distortions of the indicator $\Delta E_{ab}^*$.

As a result, we have the following results:
1. The stables zone is in the interval reduction of the image from 100% to 60%;
2. The zone reduction of the image from 60% to 30% is the last steady, stable zone where the value of the indicator $\Delta E_{ab}^*$ does not exceed 0.6. This value of the indicator is not enough, it is almost twice less concerning the recommended value $\Delta E_{ab}^*$. It is possible to tell that it is very similar to the limit for digital graphic files.

To answer the question of influence of the prevailing color of the image on indicator $\Delta E_{ab}^*$, and it makes sense to group images of different formats, depending on the prevailing color. As a result, it is possible to select the following groups of images independent of the graphic format:
1. Images with the prevailing blue color – figure 2, 5, 8, and 11;
2. Images with the prevailing green color – figure 3, 6, 9, and 12;
3. Images with the prevailing red color – figure 4, 7, 10, and 13;
Analysis of these diagrams showed, it is possible to establish that all images with the prevailing colors behave rather steadily, having above described «zones» and their sequences. However, several conclusions can be drawn nevertheless:

1. Images with the prevailing blue color it is not dependent on the graphic format behave extremely steadily and observe dynamics of «zones» described above.
2. Though it is and the only example, but the PNG format is better than the others coped with the image at which the red is the prevailing color. That can indicate that different formats differently cope with different colors on images.
3. At all other, images with the prevailing green color showed the lowest indicators $\Delta E_{ab}^*$ from all images. Besides it is the only images on which the value of the indicator $\Delta E_{ab}^*$ did not exceed 2. The maximum value $\Delta E_{ab}^*$ was about 1.43 here while the image was reduced by 90% concerning the original.

6. Conclusions
1. As show graphic dependences in Figure 2 … 13, the greatest firmness at determination of average image color the BMP format has, and its value of the indicator $\Delta E_{ab}^*$ does not exceed 2 units irrespective of images parameters.
2. The BMP format gives the chance to define average image color at 70% reduction of image size.
3. The technique of CIE-76 has always the greatest values of the indicator $\Delta E_{ab}^*$. It is revealed at all formats, irrespective of primary color on the image.
4. All other techniques of calculation of the indicator $\Delta E_{ab}^*$, show very insignificant deviations from each other and the essential difference from CIE-76 technique at stages of the maximum reduction of the image.
5. At all graphic formats, it is possible to select, so-called stable sections, however transition to them can have spasmodic character. On these stable sections, there are no jumps, and indicator $\Delta E_{ab}^*$ proves to be steadily.
6. All curves show rather identical trend in the graphs. At small reduction of the image indicator $\Delta E_{ab}^*$ does not change, and it is the most favorable zone. Then there is rather long zone of stable and low values of the indicator $\Delta E_{ab}^*$. After this zone the sharp jump follows.
7. Techniques of CIE-76, CIE-94, and CIE-2000 in general behave probably, saving the main peaks. The main deviations begin approximately at 70% reduction of the image. However, from this point the value of the indicator $\Delta E_{ab}^*$, CIE-76 determined by the technique just sharply increases, and techniques of CIE-94 and CIE-2000 behave less intensively.
8. Techniques of CIE-94 and CIE-2000 relatively each other behave very probably and almost do not differ neither in dynamics, nor on amplitude of changes.
9. The stables zone at reduction of the image is in the interval from 80% to 60%.
10. The zone at reduction of the image from 60% to 30% is the last steady, stable zone where the value of the indicator $\Delta E_{ab}^*$ does not exceed 0.6. This value of the indicator is not enough, it more than twice less than the recommended value of the indicator $\Delta E_{ab}^*$. It is possible to tell that it is the limit for digital graphic files.
11. At all other parameters, images with the prevailing green color showed the lowest values of the indicator $\Delta E_{ab}^*$ from all images. Besides it is the only images for which values of the indicator $\Delta E_{ab}^*$ did not exceed 2. The maximum value was about 1.43 here while the image was reduced by 90% concerning the original.
12. Images with the prevailing blue color exceeded values of the indicator $\Delta E_{ab}^*$ more than 2 units on average color for the JPG, TIF and PNG formats.
13. The PNG format did not undergo testing of average color on indicator $\Delta E_{ab}^*$ only for images with the prevailing blue color.
14. It is established, that the speed of process of calculation of image average color does not depend on the type of its graphic format.
15. Based on the made experiments, software by determination of image average color were created.
16. It was shown, that use of the technology, which is based on determination of image average color, can be used for problems of dynamic lighting in cinema, multimedia products, etc. This technique is especially well recommended for use in the stage post-production – at color correction on stages and light in the frame after mounting. Actually, this technique can be considered as the physical engine of lighting.

7. References

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