# Two-stage method for adaptive binarization of raster engineering drawings

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**Abstract.** The paper describes the proposed original model and the developed two-stage method for adaptive binarization of raster engineering drawings. The method allows binarization of images whose brightness histograms are not bimodal. At the same time, thin contour lines on resulting images are saved. The method is adaptive to brightness of image background. Comparative analysis of testing results of the developed method and some well-known methods for binarization raster images confirms that the proposed solutions are effective. The method was tested on a representative set of 40 different quality raster engineering drawings.

**Keywords:** drawing, binarization, brightness histogram, threshold, contour, background, local area.

## 1 Introduction

The task of raster-vector transformation of engineering drawings images requires ensuring homotopy original and result images at all stages of image processing. The binarization stage solves the problem of dividing a bitmap to a contour and a background. Binary image processing requires less computational resources and from point of view of theoretical complexity it is simpler than gray-scale image processing. This explains binarization expediency.

Literary analysis has shown that there are many threshold methods for image processing [1-5]. They describe binarization of generalized images, but they don't pay respect to the specifics of brightness distribution and contrast in engeneering drawings.

The GMT (Global Multi-stage Thresholding) [6] methodology is the most promising binarization technology for this subject domain. It provides images multistage binarization. The researches for three-section brightness histograms [7, 8] is also interesting for further development.

## 2 Formal problem statement

The bitmap drawing represents a two-dimensional matrix of raster points $R^{(*)}$ (1) .

$$R^{(*)} = \left\{ r_{ij} \right\}_{i=0,\,j=0}^{M-1,N-1} \Big| r_{ij} \in \left( C = \left\{ c_k \right\}_0^{K-1} \right) \tag{1}$$

where $r_{ij}$ is the point (i,j) of raster drawing, C is the K-colors color palette, M, N is the width and height of the image.

The color palette of a color image ($R^{(CF)}$) consists of K colors $\left\{ c_k \right\}_0^{K-1}$. The color palette of a grayscale image ($R^{(M)}$) consists of 256 tints of gray color. The color palette of a binary images $R^{(B)}$ is bicolored $\left\{ c_k \right\}_0^{1} = \left\{ 0, 1 \right\}$. Here white color coded as «0», it is a background color. And black color coded as «1», it is a contour-line color.

The purpose of a color image binarization $R^{(CF)}$ is its homotopic mapping to a binary image $\varphi : R^{(CF)} \xrightarrow{\varepsilon} R^{(B)}$ with a permissible error $\varepsilon$. The transform colored points $\left\{ r_{ij} \right\}_{i=0,j=0}^{M-1,N-1}$ to bicolored performs in accordance with the classification method to a background and a contour.

As a binarization quality criterion we selected the minimal Hamming distance between binarized $R^{(B)}$ and reference images $R^{(0)}$ (2) [9, 10].

$$\rho\left(R^{(B)}, R^{(0)}\right) = \sum_{i=1}^{M} \sum_{j=1}^{N} \left( r_{ij}^{(B)} \wedge r_{ij}^{(0)} \right) \le \varepsilon \to 0 \tag{2}$$

The image quality metrics (MSE, PSNR, CNR, SSIM) perform as measures of this distance.

## 3 Literature review

A generalized n-stages scheme for raster images binarization was proposed in [5–7]. Images of engineering drawings are a typical example of contour-line images. The qualitative binarization result for contour-line images can be obtained even with n = 2 [6]. Therefore, we will consider only two-stage binarization.

Let's imagine that a dark contrast contour and an uneven chromatic image background there is in a color drawing image (for example, it is a blueprint or tracing paper). Brightness histograms of such images are usually three-sectioned. (Fig. 1). As a rule, in such histograms the most points have brightness which there is at the vicinity of the two prevailing values $r_{\max}^{(B)}$ (for points which belong to contour) and $r_{\max}^{(T)}$ (for points which belong to background).

In this case, if the shadow zone is limited by a bottom global binarization threshold $T^{(B)}$, the points of this zone with brightness $r_{ij} < T^{(B)}$ will certainly belong to a contour. If the light zone is limited by a top global binarization threshold $T^{(T)}$, the points of this zone with brightness $r_{ij} > T^{(T)}$ will certainly belong to a background. Points with brightnes $T^{(B)} \le r_{ij} \le T^{(T)}$, to the uncertainty interval [$T^{(B)}$; $T^{(T)}$]. They need to extra classification for a contour and a background based on the brightness estimates of their local neighborhoods

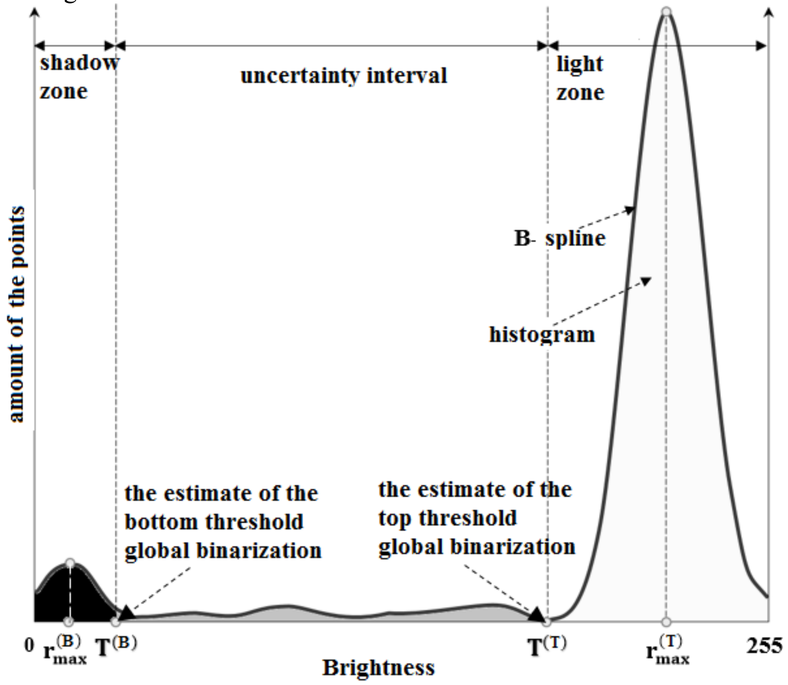


**Fig. 1.** Partioning of the brightness histogram for contour-line image in gray-scale

In [ 7, 8] a two-stage method for calculating the estimates of global thresholds is proposed for three-sectioned brightness histograms (fig. 1).

At the first stage, the lower and upper binarization thresholds are estimated. For it, we calculate minimum values of brightness for the points which belonging to the shadow or to the light zone on a brightness histogram. The solution of this task is proposed in [6], where the method QIR are described. This method allows to find the extremum of a quadratic polynomial, which approximates the brightness histogram on an information interval.

At the second stage, a final threshold value is selected as an average between the lower and the upper global thresholds. But this approach is unacceptable here. This is due to the presence of many local extremes in the brightness histograms of images with a non-uniform background (for example, drawings on tracing paper and blueprints). In addition, this approach doesn't take the mutual influence of the shadow zone and light zone when estimates of global thresholds are calculating. This leads to incomplete removal of the chromatic background from the images and to appearance of binary noise near the contour.

## 4 The proposed two-stage method for contour-line images binarization

In view of the foregoing, we proposed an adaptive two-stage binarization method for images with three-sectioned brigntness histograms. This method takes into consideration the brightness characteristics of contour-line images with a non-uniform background (tracing paper, blueprint). It includes:

- estimatimation of global binarization thresholds and search points in image those belong to the contour or background definitely;
- the points in an uncertainty interval are classificated as a contour and a background based on the local binarization thresholds estimates.

The proposed method is adaptive to the image brightness characteristics for different carrier types (drawing paper, tracing paper, blueprint) on account of injection an additional adaptive coefficient α to the formulas for a global and a local binarization thresholds calculation.

## 5 The method for global adaptive binarization thresholds estimation

The proposed method for calculating two global binarization thresholds assumes a statistical analysis of the image points brightness distribution. Further, the obtained result is adjusted depending by the drawing carrier type (drawing paper, tracing paper, blue). It includes next steps:

1. The color drawing image is converted to a grayscale image. A brightness histogram $H(n, r_{ij})$ is calculated for it [5] and approximated by cubical B-spline. This allows you to get rid of minor fluctuations in a brightness histogram of an image [11].
2. Brightness distribution of an image is analised by sizes of shadow zone and light zone in the range of its brightness. The brightness characteristics at a left (marked as «B») and a right (marked as «T») parts of the histogram are proposed to analize separately (3-6). It allows you to eliminate the mutual influence of a shadow and a light zones when the upper and the lower binarization thresholds are calculating.

$$\lim_{i\to 0} h_i = L^{(B)}_{\min} \,|\, h_i = 0,\quad \lim_{i\to 127} h_i = L^{(B)}_{\max} \,|\, h_i = 0,\quad \overline{L}^{(B)} = \frac{1}{n^{(B)}}\cdot\sum_{i=0}^{127} i\cdot h_i \tag{3}$$

$$\beta^{(B)} = \frac{\left(\overline{L}^{(B)} - L^{(B)}_{\min}\right)}{\left(L^{(B)}_{\max} - L^{(B)}_{\min}\right)},\quad \gamma^{(B)} = 1-\beta^{(B)} \tag{4}$$

$$\lim_{i\to 128} h_i = L^{(T)}_{\min} \,|\, h_i = 0,\quad \lim_{i\to 255} h_i = L^{(T)}_{\max} \,|\, h_i = 0,\quad \overline{L}^{(T)} = \frac{1}{n^{(T)}}\cdot\sum_{i=128}^{255} i\cdot h_i \tag{5}$$

$$\beta^{(T)} = \frac{\left(\overline{L}^{(T)} - L_{\min}^{(T)}\right)}{\left(L_{\max}^{(T)} - L_{\min}^{(T)}\right)}, \quad \gamma^{(T)} = 1 - \beta^{(T)} \tag{6}$$

where $h_i$ is the bin of colour «i» in the brightness histogram of an image,$n^{(B)}$, $n^{(T)}$, is the amount of points of an image which are belonged to a left or to a right part of histogram respectively, $\left[L_{\min}^{(B)}; L_{\max}^{(B)}\right]$ и $\left[L_{\min}^{(T)}; L_{\max}^{(T)}\right]$ is the ranges of brightness, $\overline{L}^{(B)}$, $\overline{L}^{(T)}$ is the average values of brightness in a left and a right part of brightness histogram respectively, $\beta^{(B)}$, $\beta^{(T)}$ is the estimates of relative sizes of a shadow zone, $\gamma^{(B)}$, $\gamma^{(T)}$ is the estimates of relative sizes of a light zone.

1. The estimates of the lower ($T^{(B)}$) and the upper ($T^{(T)}$) binarization thresholds can be calculated using the formulas (7-8).

$$T^{(B)} = \alpha^{(B)} \cdot \left(\beta^{(B)} \cdot \overline{L}^{(B)} + \gamma^{(B)} \cdot L_{\min}^{(B)}\right), \quad \alpha^{(B)} = 1 - k \cdot \beta^{(B)}, \tag{7}$$

$$T^{(T)} = \alpha^{(T)} \cdot \left(\beta^{(T)} \cdot \overline{L}^{(T)} + \gamma^{(T)} \cdot L_{\min}^{(T)}\right), \quad \alpha^{(T)} = 1 - k \cdot \beta^{(T)}, \tag{8}$$

where $\alpha^{(B)}$, $\alpha^{(T)}$, k is the tuning coefficients.

2. The method sensitivity to an image background tonality on three equiprobable carriers (blueprint, tracing paper, drawing paper) we can change using the tuning coefficients, $\alpha^{(B)}$, $\alpha^{(T)}$. Their values should be selected from the range [0,95; 1.00].

As a result, points of a drawing image $\{r_{ij}\}$ are classified to:

- Points of a binary contour $\left(r_{ij}^{(b)} = 0\right)$. Their brightness are less then the lower global binarization threshold (i.e. $r_{ij} < T^{(B)}$);
- Points of a binary background of the image $\left(r_{ij}^{(b)} = 1\right)$. Their brightness are more than the higher global binarization threshold (i.e. $r_{ij} > T^{(T)}$).

The rest of an image points are remained in an interval of uncertainty.

## 6 The method for local adaptive binarization thresholds estimation

As noted above, in brightness histograms of the images of drawings, a shadow zone less than a light zone. The bimodality of those histograms is weakly expressed. However, a bimodality at local areas of an image is more distinct. Therefore, the points of the drawing, the brightness of which is in the interval of uncertainty, are divided into points of the background and contour by the local threshold $\left\{t_m = f\left(\omega_m, L_{\omega_m}\right)\right\}$. The formula, which used for a local binarization threshold calculating, takes to account influence of the uneven distribution $L_{\omega_m}$ of the background brightness and the type of image carrier. It allows you to vary the size $d_\omega$ for each local area. A local binarization includes some steps:

1. We build local areas $\omega_m$ around each point $r_{ij}$, brightness of which belongs to uncertainty interval. We choose the points are equidistanted and centrated relatively the point $r_{ij}$. The brightness histograms of those areas are quasi-bimodal (Fig. 2).

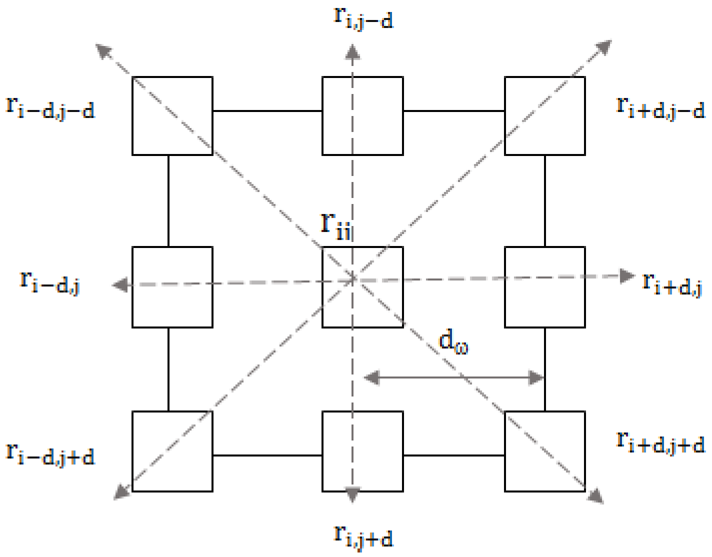


**Fig. 2.** The local $\omega_m$ area for the point $r_{ij}$ with the radius $d_\omega$

In accordance with the Gibbs principle [11], it suffices to consider only points of an image which are located along the base vectors. Their brightness has the greatest effect on a result of binarization the point $r_{ij}$.

It experimentally established [12], the thin contour lines can be binarized successful when $d_\omega \in [1; 9]$. They are usually deformed when $d_\omega > 9$. This is due to the peculiarities of a smoothed raster contour lines construction by Bretzenheim [5]. In accordance to it, the lines are depicted not only in black, some points of them are grey. Their brightness value can overcome the local binarization threshold $t_m$.

The initial value $d_\omega$ is proposed to calculate according to the expressions (9-10).

$$d_\omega = 9 \cdot \left\lceil \frac{r_{ij} - L_{\max}}{L_{\max} - L_{\min}} + 1 \right\rceil \tag{9}$$

$$\lim_{i \to 0} h_i = L_{\min} \,\middle|\, h_i = 0, \quad \lim_{i \to 255} h_i = L_{\max} \,\middle|\, h_i = 0, \quad \overline{L} = \frac{1}{n} \cdot \sum_{i=0}^{255} i \cdot h_i \tag{10}$$

So, the value of $d_\omega$ is inversely proportional to brightness of an analyzed point. It allows you to save thin contour lines after binarization.

At the next, we calculate a minimal $\left(L_{\min}^{(\omega)}\right)$, a maximal $\left(L_{\max}^{(\omega)}\right)$ and an average $\left(\overline{L}^{(\omega)}\right)$ estimates of points brightness inside the local $\omega_m$ area.

$$L_{\min}^{(\omega)} = \min\begin{pmatrix} \min\left(r_{k+i,l}\right) & \forall k \in \left[-d_\omega, d_\omega\right], l = 0, \\ \min\left(r_{k,l+j}\right) & \forall l \in \left[-d_\omega, d_\omega\right], k = 0, \\ \min\left(r_{k+i,\, l+j}\right) & \forall k, l \in \left[-d_\omega, d_\omega\right] \end{pmatrix} \tag{10}$$

$$L_{\max}^{(\omega)} = \max\begin{pmatrix} \max\left(r_{k+i,l}\right) & \forall k \in \left[-d_\omega, d_\omega\right], l = 0, \\ \max\left(r_{k,l+j}\right) & \forall l \in \left[-d_\omega, d_\omega\right], k = 0, \\ \max\left(r_{k+i,\, l+j}\right) & \forall k, l \in \left[-d_\omega, d_\omega\right] \end{pmatrix} \tag{11}$$

$$\overline{L}^{(\omega)} = \frac{1}{9 \cdot d_\omega}\left(\sum_{k=-d_\omega}^{d_\omega} r_{k+i,l} + \sum_{k=-d_\omega}^{d_\omega} r_{k,l+j} + \sum_{k=-d_\omega}^{d_\omega} r_{k+i,l+j}\right) \tag{12}$$

After that, we estimate the sizes of a shadow zone ($\beta^{(\omega)}$) and of a light zone ($\gamma^{(\omega)}$) in the local $\omega_m$ - area of the point $r_{ij}$ (14).

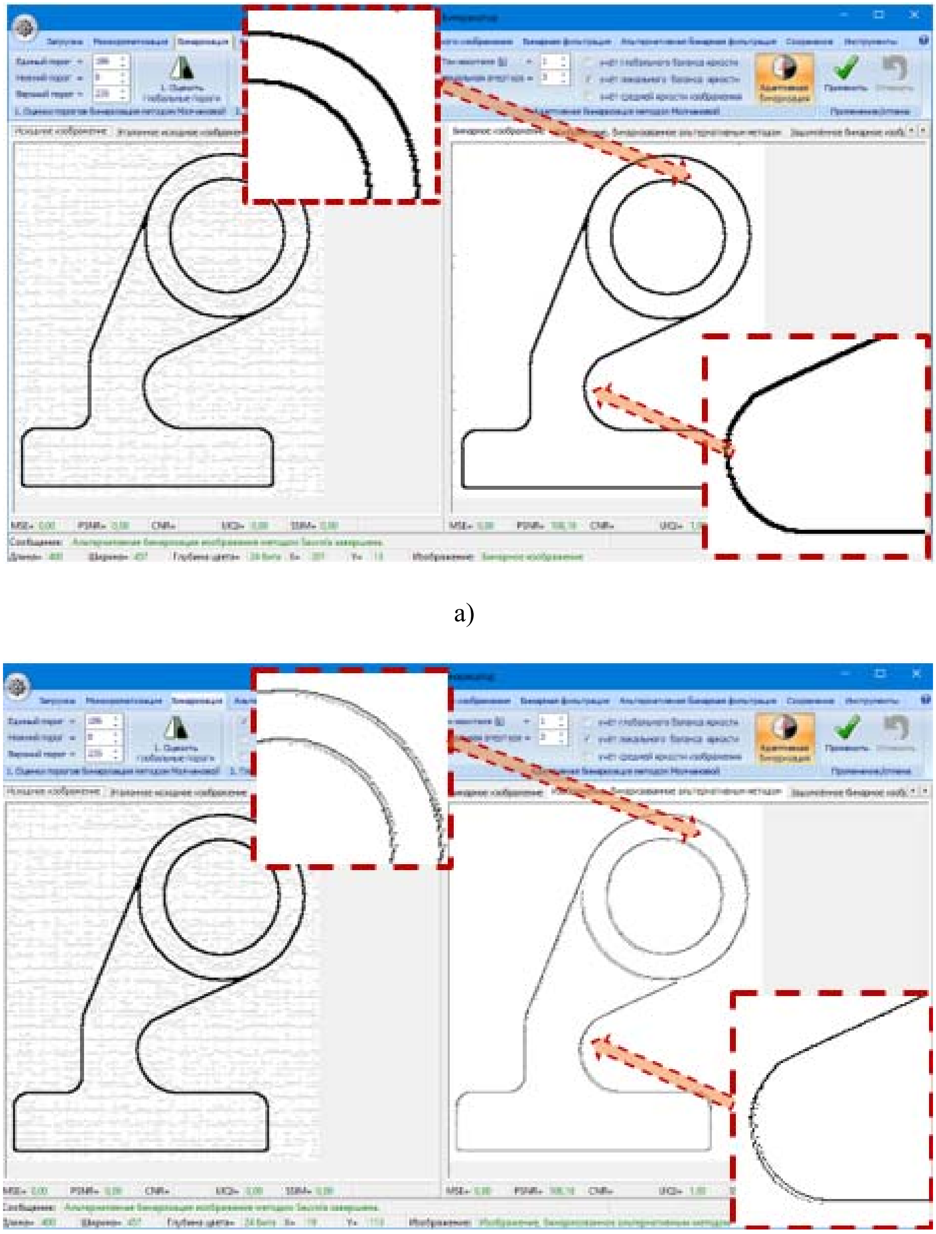
$$\beta^{(\omega)} = \frac{\overline{L}^{(\omega)} - L_{\min}^{(\omega)}}{L_{\max}^{(\omega)} - L_{\min}^{(\omega)}}, \quad \gamma^{(\omega)} = \frac{L_{\max}^{(\omega)} - \overline{L}^{(\omega)}}{L_{\max}^{(\omega)} - L_{\min}^{(\omega)}} = 1 - \beta^{(\omega)} \tag{13}$$

The local binarization threshold can be calculated by the formula (15).

$$t_m = \alpha\left(\beta^{(\omega)} \cdot \overline{L}^{(\omega)} + \gamma^{(\omega)} \cdot L_{\min}^{(\omega)}\right), \qquad \alpha = 1 - k \cdot \beta \tag{14}$$

So, the proposed method for local binarization threshold calculating is adaptive to brightness of the central point. This is ensured by the choise availability of an optimal diameter for local area of each point, which brightness value is in uncertainty zone. In addition, this method takes into account background tonality effect to the binarization result for different types of drawing carriers. So, the result binary image contains minimum number of artifacts.

We have developed an information system that shows testing results of the developed method and of some most popular alternative binarization methods. As you can see the proposed method allows you to save contour lines integrity. In this case, all artifacts near the contour are removed (Fig. 3, a). Alternative binarization methods leads to contour line doubling (Fig. 3, b).



a)

b)

**Fig. 3.** The result of the color image binarization using the developed method

## 7 Experiments and results

Analysis of the testing results of the method proposed in this work confirms that binarization quality is sufficient to preserve the topological features of the contours. We used a random sample of 40 color images of various sizes to test the method. Such sample guarantees representative results with a 95% probability when n> 23 [15] (16).

$$n = \frac{p \cdot (100 - p) \cdot t^2}{\delta^2} = \frac{15 \cdot 85 \cdot 2^2}{15^2} = 23 \tag{15}$$

where $n$ is the minimum size of sample with an unknown value of the general concurrence, p is the average error ($15\%$), t is the confidence coefficient, it shows a probability that the error will not exceed the a limit value (when t = 2 a probability of an accurate prediction is 95%), $\delta$ is the boundary error ($\pm 15\%$).

The reliability and efficiency analysis of the developed method is based on a results comparison, which we got using this method and some well-known alternative methods (Bernsen, Niblack, Otsu, Sauvola, Phansalkar). These methods usually are used for solving the similar tasks, they're generally accepted and effective.

We've chosen several general accepted metrics for results quantification: PRECISION, RECALL, F-MEASURE, ACCURACY [16]. For each image from the test sample, we repeated an experiment for 5 times, and then we averaged the results. The relative improvement of values of basic metrics for the proposed and several alternative methods is summarized in the table 1.

**Table 1.** The relative improvement of values of basic metrics for the proposed and several alternative methods

| The basic metric | The alternative method | | | | | Average by methods |
|---|---|---|---|---|---|---|
| | Bernsen | Niblack | Otsu | Sauvola | Phansalkar | |
| $\Delta \mathrm{Recall}^{AM}, \%$ | 1,70 | 0,07 | -0,08 | 8,17 | 0,22 | 2,01 |
| $\Delta \mathrm{Precision}^{AM}, \%$ | 11,02 | 81,67 | 44,42 | 3,57 | 0,45 | 28,22 |
| $\Delta F - \mathrm{measure}^{AM}, \%$ | 7,58 | 71,03 | 36,60 | 8,05 | 0,45 | 24,74 |
| $\Delta \mathrm{Accuracy}^{AM}, \%$ | 2,11 | 49,34 | 19,45 | 2,15 | 0,01 | 14,61 |
| Average performance ($\Delta M_{av}^{AM}, \%$) | 5,60 | 50,53 | 25,10 | 5,48 | 0,28 | **17,40** |

So, using the developed method to reach relative values improvement for the basic metrics of image quality by 17.4%. This allows us to make a positive conclusion about its reliability and effectiveness.

## 8 Conclusion

It has been established that the homotopic mapping of a color drawing image to a binary drawing image can be done as converting the brightness of its points to a two-color palette by classifying it as a background and a contour. The proposed method takes to account influence of brightness characteristics of images, which made on different carriers and the need to preserve the topological features of the contour (for example, small primitives and thin lines).

The proposed method allows us to significantly increase the quality quantitative indicators of the converting color images of drawings to binary ones. It includes:

- the method for global adaptive binarization thresholds estimation;
- the method for local adaptive binarization thresholds estimation.

The first method is based on the forms analysis and a light and a shadow zones ratio in the brightness histograms. This allows us to take to account the global brightness heterogeneity of the drawing images.

The second method is based on the balance of brightness analysis for areas with quasi-bimodal brightness histograms. This allows us to take to account the local brightness features of the drawing images by adaptation to different types of carriers.

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