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MATHEMATICAL AND COMPUTER MODELING

UDC 004.93

THE INTELLECTUAL ANALYSIS METHOD OF COLOR IMAGES

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ABSTRACT

Context. Automatic and automated image analysis methods used in computer graphic design, biometric identification, and military target search are now widespread. The object of the research is the process of color image analysis.

Objective. The goal of the work is to create an intelligent method of image analysis based on quantization, binarization and clustering.

Method. The proposed method for intelligent color image analysis consists of the following techniques. The technique of reducing the number of colors based on the conversion of a color image into a gray-scale image and quantization of the resulting gray-scale image improves the accuracy of image feature extraction by preventing the appearance of an excessive number of image clusters. The technique of creating a set of binary images based on binarization of a quantized gray-scale image allows increasing the speed of subsequent clustering by replacing sequential extraction of all elements of a quantized gray-scale image with parallel extraction of binary image elements, as well as separating clusters obtained during subsequent clustering by color due to image membership. The technique of determining the highest priority binary images based on the probability of occurrence of each color in the quantized gray-scale image improves the speed of image structure synthesis based on the analysis results by considering the most informative binary images. The technique of extracting binary image elements on the basis of its clustering allows to increase the accuracy of extracting binary image elements by improving the method of forming the neighborhoods of points (no radius of empirically determined neighborhood is needed), detecting random outliers and noise, extracting image elements of different shapes and sizes without specifying the number of extracted binary image elements, as well as increasing the speed of extracting binary image elements by forming the neighborhoods of white points only. The technique of determining the higher priority parts of the binary image based on the power of image clusters allows increasing the accuracy of image structure synthesis based on the analysis results by omitting noise and random outliers.

Results. The proposed method for intelligent analysis of color images was programmatically implemented using Parallel Computing Toolbox of Matlab package and investigated for the task of image feature extraction on the corresponding database. The results obtained allowed to compare the traditional and proposed methods.

Conclusions. The proposed method allows to expand the application area of color image analysis based on color-to-gray-scale image conversion, quantization, binarization, parallel clustering and contributes to the efficiency of computer systems for image classification and synthesis. Prospects for further research investigating the proposed method for a wide class of machine learning tasks.

KEYWORDS: intelligent image analysis, quantization, binarization, image feature extraction, clustering.

ABBREVIATIONS

EM is an expectation-maximization algorithm;

PAM is a partitioning around medoids algorithm;

ISODATA is an iterative self-organizing data analysis technique algorithm;

FCM is ae fuzzy classifier means algorithm;

OPTICS is an ordering points to identify the clustering structure algorithm;

DBSCAN is a density-based spatial clustering of applications with noise algorithm;

DISMEA is a divisive hierarchical clustering algorithm that uses the k-means algorithm to subdivide a cluster into two;

DIANA is a divisive analysis algorithm.

NOMENCLATURE

$A = \{A_1, ..., A_c\}$ is a correct set of image elements;

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T is a time;

n_1 is a line number of the image;

n_2 is a column number of the image;

N_1 is an end of the current row of the image;

N_2 is an end of the current column of the image;

$R(n_1, n_2)$ is a red color component;

$G(n_1, n_2)$ is a green color component;

$B(n_1, n_2)$ is a blue color component;

$y(n_1, n_2)$ is an 8-bit gray-scale image;

k is a color number;

Δ is a quantization step;

$s(n_1, n_2)$ is a quantized gray-scale image;

$M_k(n_1, n_2)$ is a point label matrix;

c_k is a counter of the number of connected regions;

i is a current point of the image;

$U_{i,\varepsilon}$ is a neighborhood of the i-th point;

v is a first element from the set S, i.e. $S = U_{i,\varepsilon}$, $v = s_1$;

m_1, m_2 are the coordinates of the v-th point in the image;

$U_{v,\varepsilon}$ is a neighborhood of the v-th point;

$z_k(n)$ is a power vector of clusters;

$Q_k(n_1, n_2)$ is a k-th binary image;

p_k is a probability of occurrence of a point with color with number k;

D is a size of Moore's neighborhood of the point;

$p_k \times N_1 \times N_2$ is a number of white dots in k-th binary image;

mod is a modulo division;

$[\ ]$ is taking the integer part of the number.

INTRODUCTION

The rapid development of computing and information technology has provided automatic or automated processing and analysis of visual information.

One of the applications of visual information analysis has become computer graphic design. To synthesize new images, components of already existing images are often used, so the problem of accurate and fast extraction of required elements of previous images is relevant [1–3].

Another application of visual information analysis was the creation of biometric personal identification systems to solve the problems of differentiating the access of users of software and hardware objects, identifying intruders and others. In this case, one of the most popular and simple in terms of technical means of identification is identification by face [4–6].

Another application of visual information analysis is the detection of military targets. Currently, the problem of accurate and fast decision making about ground targets for drones is relevant.

Nowadays, methods of automatic and automated image analysis, which use machine learning algorithms, are widespread.

The object of study is the process of color image analysis.

The subject of study is the methods for color image analysis based on digital image processing and machine learning.

The purpose of the work is to create an intelligent method of image analysis based on quantization, binarization, and clustering.

In order to achieve the goal, the following objectives were set and solved:

1) to create a technique to reduce the number of colors based on color-to-gray-scale image conversion and quantization;

2) to develop a technique for creating a set of binary images based on the binarization of a quantized gray-scale image;

3) to create a technique for determining the highest priority binary images based on the probability of occurrence of each color in the quantized gray-scale image;

4) to develop a technique for image feature extraction based on clustering of binary image;

5) to create a technique for determining the highest priority elements of a binary image based on the clustering power of that image;

6) to conduct a numerical study of the proposed method.

1 PROBLEM STATEMENT

The problem of improving the efficiency of image analysis based on clustering is represented as the problem of finding such an ordered set of image elements $A^* = \{A_1^*, ..., A_c^*\}$ in time T, at which $F = \sum_{k=1}^{c} \left\| A_i - A_i^* \right\| \to \min$ and $T \to \min$.

2 REVIEW OF THE LITERATURE

For automatic and automated image classification and synthesis, image feature extraction plays an important role, for which quantization, binarization, and image segmentation techniques can be used.

For image binarization, the approaches commonly used are [7]:

– automatic selection of a single-level local threshold (e.g., Eikwel, Bernsen, Sauvola, Niblack, Christian methods) [9];

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– automatic selection of a single-level global threshold (e.g., Otsu's method) [8].

The above methods have one or more of the following disadvantages:

– require a time-consuming thresholding procedure;

– do not perform binarization accurately enough;

– require a labor-intensive procedure for determining additional parameters.

In this regard, it is relevant to create a method of image binarization that will eliminate the mentioned disadvantages.

For image segmentation usually use such approaches as [7]:

– Markov random field based [17];

– region detection (region sprawl, region splits and merges, watershed) [11];

– definition of region boundaries (pixels with a large intensity gradient and also differing in color are selected as region boundaries) [10];

– taxonomic [12];

– based on partial derivative equations [14].

– histogram [13];

– graph-based [16];

– variational [15].

The most popular of them is the taxonomic approach.

The traditional methods of the taxonomic approach are:

1. Model mixture or model-based (e.g., EM [21]) or distribution-based methods.

2. Partitioning-based (partitioning-based, partition-based) or center-based (center-based) methods (e.g., PAM (k-medoids) [18], *k*-means [18], ISODATA [20], FCM [19] algorithms).

3. Methods are hierarchical (hierarchal).

4. Density-based methods (e.g., OPTICS [23], DBSCAN [22] algorithms).

5. Divisive or top-down (e.g., DISMEA, DIANA methods) [25].

6. Agglomerative or bottom up (e.g., Ward's methods, centroidal linkage, full linkage, single linkage, group mean) [24].

Taxonomy-based methods can also be based on metaheuristics [26] and artificial neural networks [27].

The above methods have one or more of the following disadvantages:

– require the definition of parameter values;

– do not allow to separate noise and random outliers;

– have high computational complexity;

– require specifying the number of clusters;

– clusters cannot have different shapes and sizes.

In this regard, it is relevant to create an image segmentation method that will eliminate the above disadvantages.

One of the ways to speed up segmentation is to pre-transform a color image into a gray-scale image and quantization, which reduce the number of colors [28–30].

3 MATERIALS AND METHODS

The method of intellectual analysis of a color image based on parallel clustering includes six stages (the first two stages correspond to the technique of image color reduction, the third stage corresponds to the technique of creating a set of binary images, the fourth stage corresponds to the technique of determining the highest priority binary images, the fifth stage corresponds to the technique of extracting elements of a binary image, the sixth stage corresponds to the technique of determining the highest priority elements of a binary image):

Stage 1. Converting the color image into a gray-scale image

The conversion of a color image $R(n_1, n_2), G(n_1, n_2), B(n_1, n_2)$ into an 8-bit gray-scale image $y(n_1, n_2)$ is performed using the YCrCb color space

$$y(n_1, n_2) = 0.2989 \cdot R(n_1, n_2) + \\ + 0.5870 \cdot G(n_1, n_2) + 0.1140 \cdot B(n_1, n_2), \\ n_1 \in \overline{1, N_1},\ n_2 \in \overline{1, N_2}.$$

Step 2. Quantization of gray image

1. Set the 8-bit gray-scale image $y(n_1, n_2)$, $n_1 \in \overline{1, N_1}$, $n_2 \in \overline{1, N_2}$. Set the quantization step Δ.

2. Set the line number of the image $n_1 = 1$.

3. Set the column number of the image $n_2 = 1$.

4. Set the color number $k = 1$.

5. If $k\Delta - \Delta \le y(n_1, n_2) \wedge y(n_1, n_2) < k\Delta$, then $s(n_1, n_2) = k\Delta - \Delta / 2$.

6. If not the last color, i.e. $k < 256 / \Delta$ then increase the color number, i.e. $k = k + 1$, then go to step 5.

7. If $y(n_1, n_2) = 255$, then $s(n_1, n_2) = 256 - \Delta / 2$.

8. If not the end of the current row of the image, i.e. $n_2 < N_2$, then increase the column number of the current row, i.e. $n_2 = n_2 + 1$, then go to step 4.

9. If not the last row of the image, i.e. $n_1 < N_1$, then increase the row number of the current row, i.e. $n_2 = n_2 + 1$, then go to step 3.

Step 3. Binarization of quantized gray-scale image (creation of the k-th binary image)

1. Set the quantized gray-scale image $s(n_1, n_2)$, $n_1 \in \overline{1, N_1}$, $n_2 \in \overline{1, N_2}$.

2. Perform binarization of the image in the form

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$$Q_k(n_1,n_2)=\begin{cases}1, & s(n_1,n_2)=k\Delta-\Delta/2\\ 0, & s(n_1,n_2)\neq k\Delta-\Delta/2\end{cases},$$
$$n_1\in\overline{1,N_1},\ n_2\in\overline{1,N_2}.$$

Step 4. Calculate the probability of appearance of a point with color with number k in the quantized gray image

1. Set the k-th binary image $Q_k(n_1,n_2)$, $n_1\in\overline{1,N_1}$, $n_2\in\overline{1,N_2}$.

2. Calculate the probability of appearance of a point with color with number k

$$p_k=\frac{1}{N_1N_2}\sum_{n_1=1}^{N_1}\sum_{n_2=1}^{N_2}Q_k(n_1,n_2).$$

Step 5. Clustering of the k-th binary image

1. Set the image $s(n_1,n_2)$, $n_1\in\overline{1,N_1}$, $n_2\in\overline{1,N_2}$. Set the k-th binary image $Q_k(n_1,n_2)$, $n_1\in\overline{1,N_1}$, $n_2\in\overline{1,N_2}$. Set the size of the Moore neighborhood of the point D. Set the point label matrix $M_k(n_1,n_2)=0$, $n_1\in\overline{1,N_1}$, $n_2\in\overline{1,N_2}$. Set the count of the number of clusters $c_k=0$.

2. Set the row number of the image $n_1=1$.

3. Set the image column number $n_2=1$.

4. Define the number of the current point of the image $i=(n_1-1)N_2+n_2$.

5. If the i-th point is already marked, i.e. $M_k(n_1,n_2)\neq 0$, then go to step 20.

6. Determine the neighborhood of the i-th point

$$U_{i,\varepsilon}=\{e\mid Q_k(l_1+n_1,l_2+n_2)=1\},$$
$$e=(l_1+n_1-1)N_2+l_2+n_2,\ l_1,l_2\in\{-1,0,1\}.$$

7. If not all the neighbors of the i-th point fall in its neighborhood, i.e. $|U_{i,\varepsilon}|<D$, then mark the i-th point as a random outlier or a noise, i.e. $M_k(n_1,n_2)=-1$, go to step 20.

8. Increment the counter of the number of connected regions, i.e. $c_k=c_k+1$.

9. Label the i-th point as the c_k-th cluster, i.e. $M_k(n_1,n_2)=c_k$.

10. Create the set $S=U_{i,\varepsilon}$.

11. Remove the first element from the set S, i.e. $v=s_1$, and remove it from the set S, i.e. $S=S\setminus\{v\}$.

12. Determine the coordinates of the v-th point in the image

$$m_2=v \bmod N_2,\ m_1=[(v-m_2)/N_2].$$

13. If the v-th point was labeled as a random outlier or noise, i.e. $M_k(m_1,m_2)=-1$, then label it as the c_k-th cluster, i.e. $M_k(m_1,m_2)=c_k$.

14. If the v-th point is already labeled, i.e. $M_k(m_1,m_2)\neq 0$, then proceed to step 19.

15. Label the v-th point, i.e. $M_k(m_1,m_2)=c_k$.

16. Determine the neighborhood of the v-th point

$$U_{v,\varepsilon}=\{e\mid Q_k(l_1+m_1,l_2+m_2)=1\},$$
$$e=(l_1+m_1-1)N_2+l_2+m_2,\ l_1,l_2\in\{-1,0,1\}.$$

17. If not all neighbors of the v-th point fall in its neighborhood, i.e. $|U_{v,\varepsilon}|<D$, then go to step 19.

18. Merge the set S with the neighborhood of the v-th point, i.e. $S=S\bigcup U_{v,\varepsilon}$.

19. If the set S is not empty, i.e. $|S|>0$, then go to step 11.

20. If not the end of the current row of the image, i.e. $n_2<N_2$, then increase the column number of the current row, i.e. $n_2=n_2+1$, then go to step 4.

21. If not the last row of the image, i.e. $n_1<N_1$, then increase the row number of the current row, i.e. $n_2=n_2+1$, move to step 3.

Step 6. Computing the power of clusters of the k-th binary image

1. Set the point label matrix $M_k(n_1,n_2)$, $n_1\in\overline{1,N_1}$, $n_2\in\overline{1,N_2}$. Set the number of clusters c_k. Set the power vector of clusters $z_k(n)=0$, $n\in\overline{1,c_k}$.

2. Set the row number of the image $n_1=1$.

3. Set the image column number $n_2=1$.

4. If a point belongs to a cluster, i.e. $M_k(n_1,n_2)>0$, then increase the power of the clusters, i.e. $z_k(M_k(n_1,n_2))=z_k(M_k(n_1,n_2))+1$.

5. If not the end of the current row of the image, i.e. $n_2<N_2$, then increase the column number of the current row, i.e. $n_2=n_2+1$, then go to step 4.

6. If not the last row of the image, i.e. $n_1<N_1$, then increase the row number of the current row, i.e. $n_2=n_2+1$, then go to step 3.

7. Sort the power vector of clusters in descending order, i.e. $z_k(n)\geq z_k(n+1)$.

4 EXPERIMENTS

Numerical study of the proposed method of intelligent color image analysis was carried out using Parallel Computing Toolbox of Matlab package on the basis of theatrical playbill data.

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In this work the image sizes $N_1 = 228$ and $N_2 = 165$, the quantization step $\Delta = 16$, for the white point the Moore neighborhood of size $1 \le D \le 9$.

5 RESULTS

In Fig. 1, a, the original color image is shown. According to the first step, the color image is converted to gray-scale image.

According to the second stage, in Fig. 1, b, the gray-scale image is quantized with quantization step $\Delta = 16$, i.e., the possible colors are 8, 24, 40, 56, 72, 72, 88, 104, 120, 136, 136, 152, 152, 168, 184, 200, 216, 232, 248.

According to the third stage quantized gray-scale image can be divided into $256/\Delta = 16$ binary images.

According to the fourth step the probabilities of color appearance are calculated.

In Fig. 3 binary images corresponding to colors with the highest probability of occurrence are presented with indication of their number k, color and probability of occurrence p_k.

Figure 1 – The color image

Figure 2 – The gray image from $\Delta = 16$

Figure 3 – The binary image: a – $k = 1$ (color 8, $p_1 = 0.467$); b – $k = 11$ (color 168, $p_{11} = 0.126$); c – $k = 13$ (color 200, $p_{13} = 0.062$); d – $k = 16$ (color 248, $p_{16} = 0.159$)

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In accordance with the fifth stage, parallel clustering of binary images is performed. The binary image corresponding to the color with the highest probability of occurrence, which is shown in Fig. 3a, was chosen as an example.

According to the sixth step, the power of clusters is calculated. In Fig. 4 the most powerful clusters are presented with their number n and power $z_k(n)$ with the size of Moore's neighborhood $D = 4.5$.

In Fig. 5, the most powerful clusters are shown with their number n and power $z_k(n)$ with the size of the cluster Moore's neighborhood $D = 9$ stands out more accurately.

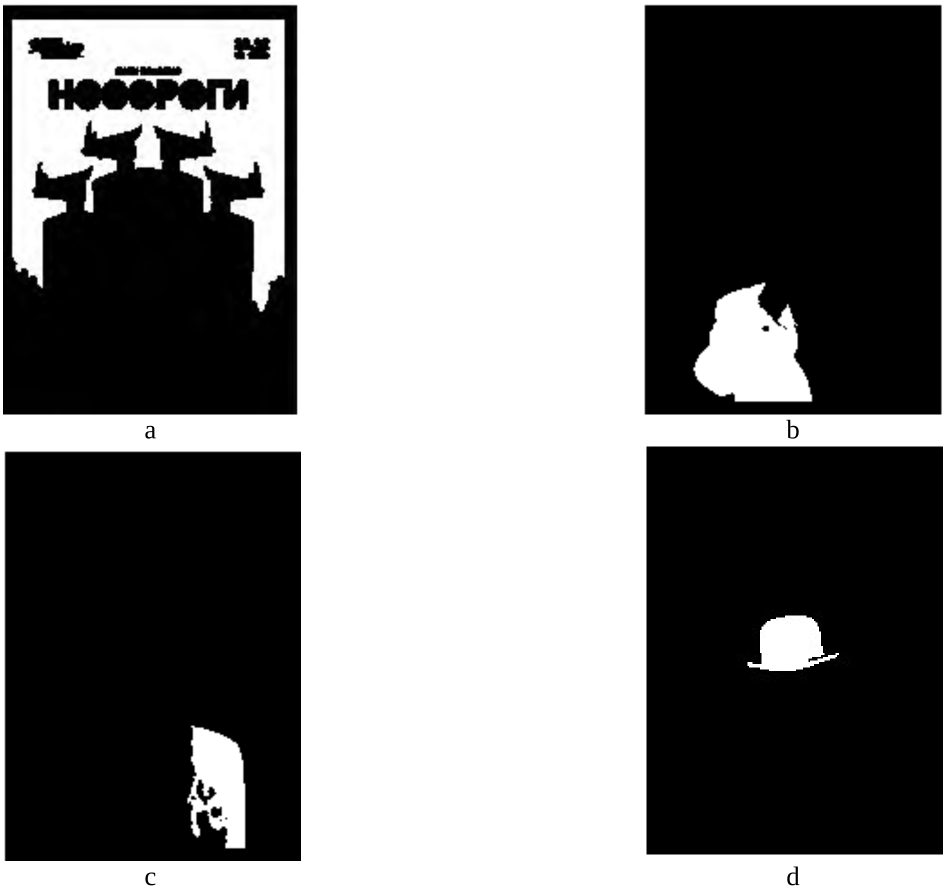

Figure 4 – The cluster:
a – $n = 1$ ($D = 4.5$, $z_1(1) = 11921$) ; b – $n = 2$ ($D = 4.5$, $z_1(2) = 2829$) ;
c – $n = 3$ ($D = 4.5$, $z_1(3) = 1454$) ; d – $n = 4$ ($D = 4.5$, $z_1(4) = 973$)

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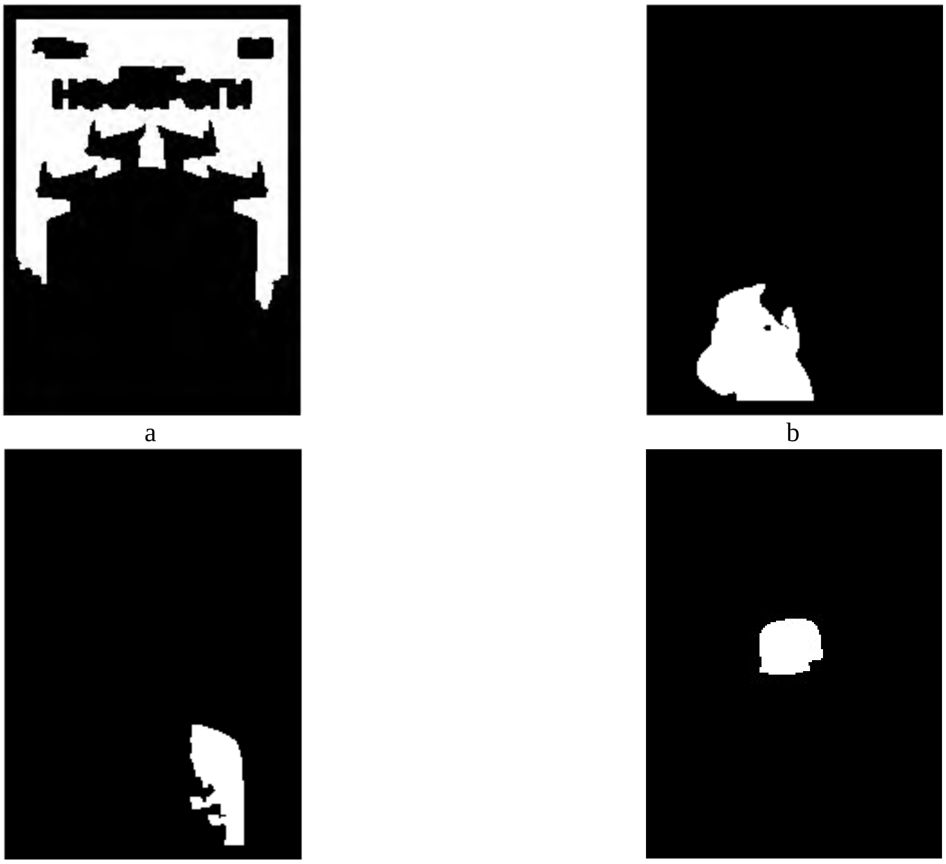

Figure 5 – The cluster:
a – $n=1\,(D=9,\ z_1(1)=11564)$; b – $n=2\,(D=9,\ z_1(2)=2817)$;
c – $n=3\,(D=4.5,\ z_1(3)=1341)$; d – $n=4\,(D=9,\ z_1(4)=920)$

The comparison results of the proposed parallel clustering based intelligent image analysis method with the existing DBSCAN method are shown in Table 1.

Table 1 – Comparison of the proposed intelligent image analysis method based on parallel clustering with the existing DBSCAN method

Accuracy		Computational complexity	
proposed	existing	proposed	existing
0.98	0.85	$(p_k \times N_1 \times N_2)^2$	$(N_1 \times N_2)^2$

6 DISCUSSION

The existing DBSCAN method, which refers to density clustering and extracts connected regions:

– has high computational complexity;

– does not allow parallel processing;

– does not guarantee strict partitioning of image clusters by color;

– can lead to an excessive number of clusters in case of a large variety of image colors;

– requires setting the neighborhood radius, incorrect setting of which may reduce the clustering accuracy.

Therefore, in this paper we proposed a method for intelligent analysis of color images, which instead of a long clustering of a single image goes to a set of binary images (each binary image contains only elements of the quantized gray image with the same color, and these elements in the binary image are highlighted in white), the extraction of elements of which during clustering occurs in parallel, and during clustering the formation of neighborhoods only points of white color are checked. Since the clusters associated with a single binary image correspond to a certain color of the quantized gray image, there is a partitioning of clusters by color. Since in the proposed method there is a preliminary conversion of color image to gray-scale image and then the gray-scale image is quantized, i.e., the number of colors is reduced, there is

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no excessive number of image clusters. Since the proposed method clusters binary images and only white color points are considered, instead of neighborhood radius, white color check of neighborhood points is used, which improves the accuracy of clustering.

Thus, the proposed method eliminates the mentioned disadvantages of the existing method.

The selected parameter values of the proposed method of intelligent color image analysis provide high accuracy of image elements extraction (Fig. 3a) and speed of this extraction (Fig. 3a), compared to the existing DBSCAN method.

According to Fig. 4 and Fig. 5 in case of Moore's neighborhood size $D = 4.5$, the elements of binary image are extracted more accurately.

CONCLUSIONS

The actual problem of improving the efficiency of color image analysis methods was solved by creating a method based on digital image processing and clustering algorithms.

The scientific novelty.

1. The proposed method of intelligent analysis of color images allows to increase the accuracy and speed of image elements extraction due to digital pre-processing and parallel clustering.

2. The technique of reducing the number of colors on the basis of color image conversion to gray-scale and quantization of the resulting gray-scale image allows increasing the accuracy of image elements extraction by preventing the appearance of an excessive number of image clusters.

3. The technique of creating a set of binary images on the basis of quantized gray image binarization (each binary image contains only elements of the quantized gray image with the corresponding same color, and these elements in the binary image are highlighted in white) allows to increase the speed of further clustering by replacing the sequential extraction of all elements of the quantized gray image by parallel extraction of elements of binary images, as well as to break the clusters obtained in the course of further clustering of the quantized gray image.

4. The technique of determining the highest priority binary images based on the probability of occurrence of each color in the quantized gray-scale image allows increasing the speed of image structure synthesis from the analysis results by considering the most informative binary images.

5. The technique of extracting binary image elements on the basis of its clustering allows to increase the accuracy of extracting binary image elements by improving the method of point neighborhood formation (to include a white point in the neighborhood of the point, the points nearest to it are simply checked for white color, so no empirically determined neighborhood radius is required). detecting random outliers and noise (minimum power cluster), extracting image elements of different shapes and sizes (due to connectivity), not specifying the number of and

6. The technique of determining the highest priority elements of a binary image based on the power of clusters of this image allows increasing the accuracy of image structure synthesis based on the analysis results by omitting noise and random outliers.

The practical significance. The proposed method extends the application area of color image analysis based on color-to-gray-scale image conversion, quantization, binarization, parallel clustering, and contributes to the efficiency of computer-based image classification and synthesis systems.

Prospects for further research are the study of the proposed method for a wide class of artificial intelligence tasks.

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МЕТОД ІНТЕЛЕКТУАЛЬНОГО АНАЛІЗУ КОЛЬОРОВИХ ЗОБРАЖЕНЬ

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АНОТАЦІЯ

Актуальність. В даний час широкого поширення набули методи автоматичного та автоматизованого аналізу зображень, які використовуються в комп'ютерному графічному дизайні, біометричній ідентифікації, пошуку військових цілей. Об'єктом дослідження є процес аналізу кольорових зображень.

Метою роботи є створення інтелектуального методу аналізу зображення на основі квантування, бінаризації та кластеризації.

Метод. Запропонований метод інтелектуального аналізу кольорових зображень складається з таких методик. Методика зменшення кількості кольорів на основі перетворення кольорового зображення в сіре та квантування отриманого сірого зображення дозволяє підвищити точність вилучення елементів зображення за рахунок запобігання появі надлишкової кількості кластерів зображення. Методика створення набору бінарних зображень на основі бінаризації квантованого сірого зображення дозволяє підвищити швидкість подальшої кластеризації за рахунок заміни послідовного вилучення всіх елементів квантованого сірого зображення паралельним вилученням елементів бінарних зображень, а також розбити кластери, отримані в ході подальшої кластеризації, за кольором за рахунок належності різним бінарним зображенням. Методика визначення найбільш пріоритетних бінарних зображень на основі ймовірності появи кожного кольору в квантованому сірому зображенні дозволяє підвищити швидкість синтезу структури зображення за результатами аналізу за рахунок розгляду найбільш інформативних бінарних зображень. Методика вилучення елементів бінарного зображення на основі його кластеризації дозволяє підвищити точність вилучення елементів бінарного зображення за рахунок поліпшення способу формування околиць точок (не потрібний радіус околиці, що емпірично визначається), виявлення випадкових викидів і шуму, видобування елементів зображення різної форми та розміру, не вказуючи кількість видобутих елементів бінарного зображення, а також підвищення швидкості вилучення елементів бінарного зображення за рахунок формування околиць тільки точок білого кольору. Методика визначення найбільш пріоритетних елементів бінарного зображення на основі потужності кластерів зображення дозволяє підвищити точність синтезу структури зображення за результатами аналізу за рахунок пропуску шуму і випадкових викидів.

Результати. Запропонований метод інтелектуального аналізу кольорових зображень був програмно реалізований за допомогою Parallel Computing Toolbox пакету Matlab і досліджений для завдання вилучення елементів зображень на відповідній базі даних. Отримані результати дозволили порівняти традиційний та запропонований методи.

Висновки. Запропонований метод дозволяє розширити область застосування аналізу кольорових зображень на основі перетворення кольорового зображення в сіре, квантування, бінаризації, паралельної кластеризації, та сприяє підвищенню ефективності комп'ютерних систем класифікації та синтезу зображень. Перспективами подальших досліджень є дослідження запропонованого методу для широкого класу задач машинного навчання.

КЛЮЧОВІ СЛОВА: інтелектуальний аналіз зображення, квантування, бінаризація, вилучення елементів зображення, кластеризація.

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