1. Introduction

Information that characterizes the person’s unique biological characteristics is most valuable when designing biometric identification systems for solving problems of access control for users of software and hardware facilities, because it allows for direct identification of a person.

Previously, for objective reasons, many of the biometric parameters of a person that would unambiguously allow the determination of their image and were difficult to fake could not be used for registration. This is, firstly, because there was no information about the possibility of identifying a person by a certain biometric parameter, and, secondly, because there were no methods and means of recording and researching relevant biometric data.

To date, a theoretical basis for the identification of a person using their biometric parameters has already been created. Moreover, methods and techniques for automation of recording and researching of the process of identifying a person that were previously absent have also been developed.

Currently, methods of automatic and automated biometric identification by voice, face, fingerprints, handwriting, palm vein pattern, iris, etc., which are based on artificial intelligence approaches, are widely used. Wherein one of the most popular and simple methods in terms of technical means of identification is face identification.
Existing face recognition systems for biometric identification of a person include the following steps:
- face detection;
- face alignment;
- facial features extraction;
- face classification.

The most important, in terms of obtaining a high-quality final result, is the face detection stage. It is this stage that is reviewed in this paper.

Existing face detection systems are based on techniques grounded on:
- knowledge;
- invariant features;
- template matching;
- appearances (they include FindFace – one of the best techniques today, which is based on a convolutional neural network).

The disadvantage of techniques based on knowledge is the limited formalized empirical knowledge of the human face.

The disadvantages of techniques based on invariant features are high sensitivity to changes in lighting, noise.

The disadvantages of techniques based on template matching are high sensitivity to changes in the scale, orientation and shape of the face, changes in lighting, noise, high computational complexity, high power of the training set.

The disadvantages of techniques based on the appearance are high computational complexity, high power of the training set.

Thus, the problem of insufficient effectiveness of face detection in the image is currently relevant.

2. Literature review and problem statement

Face determination in the image plays an important role in automatic [1] and automated [2] biometric identification, for which methods of binarization, scaling and segmentation of the image can be used.

In [3], the results of studies related to image binarization are presented. It shows that image binarization is usually based on an automatically selected single-level:
- global threshold (for example, the Otsu’s method) [4];
- local threshold (for example, Bunsen’s, Akvel’s, Niblack’s, Sauvola’s, Christian’s methods) [5].

However, issues related to improving the efficiency of threshold processing remained unresolved. The reason for this may be:
- insufficient accuracy of the binarization;
- the complexity of the procedure for determining the threshold value;
- the complexity of the procedure for determining additional parameters.

An option to overcome the corresponding difficulties may be to use a priori information about the binarizable image. This approach was used in [6], but it is applicable only to mammograms. All this suggests that it is advisable to conduct a study on the creation of an image binarization method.

The work [7] presents the results of studies related to image segmentation. According to it, the following approaches are usually used for image segmentation:
- regions boundaries determination (pixels with a large intensity gradient, as well as pixels differing in color, are selected as the regions boundaries) [8];
- regions identification (regional growth, division and merging of regions, watershed) [9];
- histogram [10];
- based on partial differential equations [11];
- variation [12];
- graph [13];
- based on the Markov random field [14].

However, the issues related to improving the efficiency of the detected areas remained unresolved. The reason for this can be:
- insufficient accuracy of the performed segmentation;
- high computational complexity of segmentation;
- the complexity of the procedure for determining additional parameters.

An option to overcome the corresponding difficulties may be to use a taxonomic approach.

Traditional methods of the taxonomic approach are:
1) methods based on partitioning (partition-based, partitioning-based) or center (center-based) (for example, k-means [15], PAM (k-medoids) [16], FCM [17], ISODATA [18]);
2) methods of model mixture or distribution-based or model-based (for example, EM [19]);
3) density-based methods (for example, DBSCAN [20], OPTICS [21] methods);
4) hierarchical methods:
   - agglomerative or bottom up (for example, centroid communication, Ward, single communication, full communication, group average methods) [22];
   - divisive or descending (top down) (for example, the DIANA [23], DISMEA [24] methods).

Taxonomic approaches can also be based on metaheuristics [25] and artificial neural networks [26].

However, these methods have one or more of the following disadvantages:
- possess high computational complexity;
- don’t allow separating noise and outliers;
- clusters can’t have different shapes and sizes;
- require setting the number of clusters;
- require the determination of parameter values.

All this suggests that it is advisable to conduct a study on the creation of an image segmentation method.

The work [27] presents the results of studies related to image scaling, which allows for image size reduction. It has been shown that the nearest neighbor method is often used to scale images [28]. However, the issues related to improving compression efficiency remained unresolved. The reason for this may be the low quality of restored images.

An option to overcome the corresponding difficulties may be to use an approach based on the following methods:
- filtering (bilinear, bicubic, Lanczos filters, etc.) [29];
- supersampling (oversampling, mipmap) [30];
- spectral transformations [31].

Still, these methods have one or more of the following disadvantages:
- high computational complexity of scaling;
- requirement to determine the additional parameters values.

All this suggests that it is advisable to conduct a study on the creation of an image scaling method.

Thus, to improve the efficiency of the technique for face detection in the image, it is necessary to improve the binarization, scaling and segmentation methods.
3. The aim and objectives of the study

The aim of this work is the development of a face detection technique based on digital signal processing and clustering methods. This makes it possible to improve the quality of face detection in the image.

To achieve the aim, the following objectives were set:
- develop an image binarization method based on image background;
- develop a binary image scaling method;
- develop a binary scaled image segmentation method based on density clustering.

4. Image binarization based on image background

The proposed image binarization based on image background includes the following steps:
1. Set the 8-bit image \( s(n_i, n_j) \), \( n_i \in \overline{1,N_i} \), \( n_j \in \overline{1,N_j} \). Set the 8-bit background image \( \tilde{s}(n_i, n_j) \), \( n_i \in \overline{1,N_i} \), \( n_j \in \overline{1,N_j} \).
2. Form the alphabet of background symbols (8-bit pixel values)
   \[
   A = \bigcup_{n_i=1}^{N_i} \bigcup_{n_j=1}^{N_j} \{ \tilde{s}(n_i, n_j) \}.
   \]
3. Perform the image binarization in the form of
   \[
   b(n_i, n_j) = \begin{cases} 
   1, & s(n_i, n_j) \in A, \\
   0, & s(n_i, n_j) \notin A, 
   \end{cases}
   \]
   \( n_i \in \overline{1,N_i}, n_j \in \overline{1,N_j} \).

As a result, the binary image is formed.

The stages, input and output data of the image binarization method are presented in Fig. 1.

Fig. 1. Structure of the image binarization method

The advantage of the proposed method of image binarization is that, unlike other methods of binarization, it allows simplifying the processes of scaling and segmentation (since all background pixels are represented in one color) and does not require a threshold setting.

5. Binary image scaling

The paper proposes two versions of the method for binary image scaling (based on filtering and based on two-dimensional fast wavelet transform). Determining the best version of the method is performed on the results of numerical study on a specific benchmark.

5.1. Binary image scaling based on arithmetic mean filter and threshold processing

The proposed binary image scaling based on arithmetic mean filter and threshold processing includes the following steps:
1) set the binary image \( b(n_i, n_j), n_i \in \overline{1,N_i}, n_j \in \overline{1,N_j} \). Set the scaling parameter \( P \) that defines the length of a square window as \( 2^P \). Set the threshold value \( T \);
2) set the row number of the binary scaled image \( n_1=1 \);
3) set the column number of the binary scaled image \( n_2=1 \);
4) calculate the average pixel value in a window of size \( 2^P \times 2^P \);
   \[
   \mu(n_i, n_j) = \frac{1}{2^{2P}} \sum_{l=1}^{2^P} b(l, l_i),
   \]
   \( l_i \in (n_i-1)2^P+1, (n_i-1)2^P+2^P \);
   \( l_j \in (n_j-1)2^P+1, (n_j-1)2^P+2^P \);
5) perform the conversion of a binary image in the form of
   \[
   b(n_i, n_j) = \begin{cases} 
   1, & \mu(n_i, n_j) > T, \\
   0, & \mu(n_i, n_j) \leq T.
   \end{cases}
   \]
6) if it is not the end of the current row of the binary scaled image, i.e. \( n_2 < N_2/2^P \), then increase the column number of the current row of the binary scaled image, i.e. \( n_2 = n_2 + 1 \), go to step 4;
7) if it is not the last row of the binary scaled image, i.e. \( n_2 = N_2/2^P \), then increase the row number of the binary scaled image, i.e. \( n_1 = n_1 + 1 \), go to step 3.

As a result, the binary scaled image is formed.

The stages, input and output data of the binary image scaling method are presented in Fig. 2.

binary image scaling parameter \( r \), threshold value \( T \) →

1. Calculate the average value of each pixel

2. Convert binary image

binary scaled image

Fig. 2. Structure of the binary image scaling method based on arithmetic mean filter and threshold processing

5.2. Binary image scaling based on two-dimensional fast wavelet transform

The proposed binary image scaling based on two-dimensional fast wavelet transform (FWT) includes the following steps:
1) set the binary image \( b(n_i, n_j), n_i \in \overline{1,N_i}, n_j \in \overline{1,N_j} \). Set the scaling parameter \( P \) that determines the number of decomposition levels. Set the number of decomposition level \( i=1 \);
2) for each row \( x \), \( x \in 0, N_x/2^i - 1 \), at the current \( i \)th level of decomposition, this row is convolved with the transition functions FIR-HPF and FIR-LPF \( g(k) \), \( h(k) \) respectively
   \[
   \tilde{g}(x, m) = \sqrt{2} \sum_{k=0}^{N_y/2^i} c_{-1}(x, k) g(k + 2m), m \in 0, N_y/2^i - 1.
   \]
\[ c_i(x,m) = \sqrt{2} \sum_{k=0}^{N_i/2-1} c_{i-1}(x,k) h(k+2m), \quad m \in 0, N_j/2 - 1, \]

where

\[ c_0(x-1,y-1) = b(x,y); \]

3) For each column \(g, y \in 0, N_j/2 - 1\), at the current \(r^{th}\) level of decomposition, this column is convolved with the transition functions FIR-HPF and FIR-LPF \(g(k), h(k)\) respectively

\[ d_r^{(2)}(m,y) = \sqrt{2} \sum_{k=0}^{N_i/2-1} d_{r-1}(k,y) g(k+2m), \quad m \in 0, N_j/2 - 1; \]

\[ d_r^{(1)}(m,y) = \sqrt{2} \sum_{k=0}^{N_i/2-1} d_{r-1}(k,y) h(k+2m), \quad m \in 0, N_j/2 - 1; \]

\[ d_r^{(0)}(m,y) = \sqrt{2} \sum_{k=0}^{N_i/2-1} c_i(k,y) g(k+2m), \quad m \in 0, N_j/2 - 1; \]

\[ c_i(m,y) = \sqrt{2} \sum_{k=0}^{N_i/2-1} c_{i-1}(k,y) h(k+2m), \quad m \in 0, N_j/2 - 1. \]

4) If \(i \neq P\), then \(i = i + 1\), go to step 1;

5) Convert the values of the approximating coefficients to the range of values \([0, 1]\)

\[ c_{\text{min}} = \min_{x,y} c_p(x,y), \quad x \in 0, N_i/2 - 1, \quad y \in 0, N_j/2 - 1; \]

\[ c_{\text{max}} = \max_{x,y} c_p(x,y), \quad x \in 0, N_i/2 - 1, \quad y \in 0, N_j/2 - 1; \]

\[ b(x+1,y+1) = \text{round} \left( c_p(x,y) - c_{\text{min}} \right) / \left( c_{\text{max}} - c_{\text{min}} \right), \quad x \in 0, N_i/2 - 1, \quad y \in 0, N_j/2 - 1, \]

where \(\text{round}(x)\) is the rounded \(x\).

As a result, the binary scaled image is formed.

The stages, input and output data of the binary image scaling method are presented in Fig. 3.

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The advantage of the image scaling method (Fig. 2, 3) is that, unlike other scaling methods, it allows to speed up the process of image segmentation by about \(P^2\) times, where \(P\) is the scaling parameter.

6. Segmentation of a binary scaled image based on density clustering

The proposed segmentation of the binary scaled image includes the following steps:

1) Set the binary scaled image \(b(n_i,n_j), n_i, n_j \in 1, N_i, \quad n_i, n_j \in 1, N_j, \quad N_j = N_i/2^r, \quad N_j = N_i/2^r\). Set the size of the pixel neighborhood \(D\) (in the case of Moore neighborhood \(D=9\)). Initialize the matrix of pixel markings \(g(n_i, n_j) = 0, \quad n_i, n_j \in 1, N_i, \quad n_i, n_j \in 1, N_j, \quad N_j = N_i/2^r, \quad N_j = N_i/2^r\)...

2) Set the image row number \(n_i = 1\);

3) Set the image column number \(n_j = 1\);

4) Calculate the number of connected components counter \(c = 0\);

5) Calculate the number of the current pixel \(i = (n_i - 1) N_j + n_j\);

6) Determine the \(i\)th pixel neighborhood

\[ U_i = \left\{ e | b(l_i + n_j l_j + n_j) = 1 \right\}; \]

\[ e = (l_i + n_j - 1) N_j + l_j + n_j, \]

\[ l_i \in \{-1, 0, 1\}, \quad l_j \in \{-1, 0, 1\}; \]

7) If not all neighbors of the pixel fall into its neighborhood, i.e. \(U_i = D_i\), then go to step 20;

8) Increase the counter of the current number of connected components \(c = c + 1\);

9) Mark the \(i\)th pixel as noise or outliers, i.e. \(g(n_i, n_j) = -1\), then go to step 20;

10) Set the \(i\)th pixel as noise or outliers, i.e. \(g(n_i, n_j) = -1\), then go to step 19;

11) Extract 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 \(i\)th pixel in the image

\[ m_2 = v \mod N_j, \quad m_1 = \left[ (v - m_2) / N_j \right]; \]

where \([\cdot]\) – taking the integer part of the number, \(\mod\) – modular division;

13) If the \(i\)th pixel was marked as noise or outliers, i.e. \(g(m_1, m_2) = -1\), then go to step 19;

14) If the \(i\)th pixel is already marked, i.e. \(g(m_1, m_2) = c\), then go to step 19;

15) Mark the \(i\)th pixel, i.e. \(g(m_1, m_2) = c\);

16) Determine the \(i\)th pixel neighborhood

\[ U_i = \left\{ e | b(l_i + m_i l_j + m_j) = 1 \right\}; \]

\[ e = (l_i + m_j - 1) N_j + l_j + m_j, \]

\[ l_i \in \{-1, 0, 1\}, \quad l_j \in \{-1, 0, 1\}; \]

17) If not all neighbors of the \(i\)th pixel fall into its neighborhood, i.e. \(U_i = D_i\), then go to step 19;

18) Combine the set \(S\) with the neighborhood of the \(i\)th pixel, i.e. \(S = S \cup U_i\).
19) if the set \( S \) still contains pixels, i.e. \( |S| > 0 \), then go to step 11;
20) if it is not the end of the current image row, i.e. \( n_1 < N_2 \), then increase the column number of the current image row, i.e. \( n_2 = n_2 + 1 \), go to step 4;
21) if it is not the last image row, i.e. \( n_1 < N_1 \), then increase the image row number, i.e. \( n_1 = n_1 + 1 \), go to step 3.

As a result, the matrix of pixel markings of a segmented binary scaled image is formed.

The stages, input and output data of the binary scaled image segmentation method are presented in Fig. 4.

![Fig. 4. Structure of the binary scaled image segmentation method](image)

The advantage of the image segmentation method is that it allows to separate noise or outliers from the face, does not require additional parameters. It also allows clusters to have different shapes and sizes, and does not require setting the number of clusters.

7. Determining the largest connected component of a binary scaled image that matches the face

The proposed determination of the largest connected component of the binary scaled image includes the following steps:
1) set the pixel markings matrix \( g(n_1, n_2) \), \( n_1 \in 1, N_1 \), \( n_2 \in 1, N_2 \), where \( N_1 = N_1 / 2^p \), \( N_2 = N_2 / 2^p \). Set the number of the connected components \( c \). Initialize the vector of size counters of the connected components \( z(n) = 0, n \in \mathbb{I}, c \);
2) set the row number of the pixel markings matrix \( n_1 = 1 \);
3) set the column number of the pixel markings matrix \( n_2 = 1 \);
4) if the binary pixel belongs to the connected component, i.e. \( g(n_1, n_2) > 0 \), then increase the size counter of the connected components, i.e. \( z(g(n_1, n_2)) = z(g(n_1, n_2)) + 1 \);
5) if it is not the end of the current row of the pixel markings matrix, i.e. \( n_2 < N_2 \), then increase the column number of the current row of the pixel markings matrix, i.e. \( n_2 = n_2 + 1 \), go to step 4;
6) if it is not the last row of the pixel markings matrix, i.e. \( n_1 < N_1 \), then increase the row number of the pixel markings matrix, i.e. \( n_1 = n_1 + 1 \), go to step 3;
7) determine the number of the largest connected component

\[ c' = \arg \max_z z(n), \quad n \in \mathbb{I}, c. \]

As a result, the number of the largest connected component of the binary scaled image that matches the face is determined.

8. Determination of the matrix of pixels belonging to the face

1. Set the pixel markings matrix \( g(n_1, n_2) \), \( n_1 \in 1, N_1 \), \( n_2 \in 1, N_2 \), \( N_1 = N_1 / 2^p \), \( N_2 = N_2 / 2^p \). Set the number of the largest connected component \( c \). Set the scaling parameter \( P \).
2. Set the row number of the pixel markings matrix \( n_1 = 1 \).
3. Set the column number of the pixel markings matrix \( n_2 = 1 \).
4. Calculate the elements of the matrix of the pixels belonging to the face

\[ h(i, j) = \begin{cases} 1 & g(n_1, n_2) = c' \smallskip 0 & g(n_1, n_2) \neq c' \end{cases} \]

\[ l_1 = (n_1 - 1)2^p + 1, (n_2 - 1)2^p + 2^p \]

\[ l_2 = (n_1 - 1)2^p + 1, (n_2 - 1)2^p + 2^p. \]

5. If it is not the end of the current row of the pixel markings matrix, i.e. \( n_2 < N_2 \), then increase the column number of the current row of the pixel markings matrix, i.e. \( n_2 = n_2 + 1 \), go to step 4.
6. If it is not the last row of the pixel markings matrix, i.e. \( n_1 < N_1 \), then increase the row number of the pixel markings matrix, i.e. \( n_1 = n_1 + 1 \), go to step 3.
As a result, the matrix of pixels belonging to the face is formed.

9. Results of experimental studies of face detection in the image using the developed technique

In the work, the proposed technique for face detection in the image was investigated.

Fig. 5. a shows the original 8-bit image. Image size is 1024×1024 pixels.

Fig. 5. b shows the resulting 8-bit image that does not use scaling (P=0).

According to the experiments for the images shown in Fig. 6, a–f, for scaling using an arithmetic mean filter with threshold processing, the value of the scaling parameter should be P=2 (at higher P, a significant change in the shape of the face begins, which can already be seen from Fig. 6, c).

For both methods, such a value of the scaling parameter P, on the one hand, does not lead to significant changes in the shape of the face (this is typical for values 3–6), which impair visual perception, and, on the other hand, does not significantly slow down segmentation (this is typical for 1).

According to the experiments that are presented in Fig. 7, a–f, to scale an image using fast wavelet transform by means of the Daubechies wavelet of length 8 (denoted by db4), the value of the scaling parameter should be P=2 (at higher P, a significant change in the shape of the face and the appearance of unwanted artifacts like gray color begin, which can already be seen from Fig. 7, c).

Table 1 presents error probabilities of the first and second kind upon face detection, obtained using the Sib-
The advantage of the image binarization method is that it simplifies the process of scaling and segmentation (since all the pixels in the background are represented in the same color) and does not require a threshold setting.

The disadvantage of the image binarization method is that it can lead to noise or outliers.

The advantage of the image segmentation method is that it allows to separate noise or outliers from the face, does not require additional parameters. It also allows clusters to have different shapes and sizes, and does not require setting the number of clusters.

The disadvantage of the image segmentation method is that it has computational complexity $O(N_xN_y)$, where $N_x \times N_y$ is the size of the scaled binary image.

The proposed methods are useful in face detection in the image, and they can be used in visual image recognition systems.

The proposed methods are a continuation of a previously conducted study on the analysis of mammograms, and in the future they are planned to be improved to further reduce computational complexity through the use of parallel information processing technology.

According to Table 1, the proposed technique, due to improved binarization, scaling, and segmentation, improves the quality of the solution to the problem of insufficient efficiency of face detection in the image.

This technique's limitation may be blurring the border of the face and background in the image (there are no pixels that are unique to the face among the boundary pixels of the face) and the image size, which is significantly larger than $1,024 \times 1,024$.

### 11. Conclusions

1. A binarization method is proposed, the distinction of which is the use of the image background. This allows to simplify the process of scaling and segmentation (since all the pixels in the background are represented in the same color), non-uniform brightness of the face, and not to use the threshold setting and additional parameters.

2. A binary image scaling method is proposed, the distinction of which is the use of an arithmetic mean filter with threshold processing and fast wavelet transform. This allows to speed up the process of image segmentation by about $P^2$ times, where $P$ is the scaling parameter, and not to use the time-consuming procedure for determining additional parameters.

3. A binary scaled image segmentation method is proposed, the distinction of which is the use of density clustering. This allows to separate areas of the face of non-uniform brightness from the image background, noise and outliers. It also allows clusters to have different shapes and sizes, to not require setting the number of clusters and additional parameters.
References

1. Nechyporenko, O. V., Korpan, Y. V. (2016). Biometric identification and authentication of persons for geometry face. Herald of Khmelnytskyi national university, 4, 133–138. Available at: http://journals.khnu.km.ua/vestnik/pdf/tech/pdfbase/2016/2016_4/239%202016-t.pdf
2. Nechyporenko, O., Korpan, Y. (2017). Analysis of methods and technologies of human face recognition. Technology Audit and Production Reserves, 5 (2 (37)), 4–10. doi: https://doi.org/10.15587/2312-8372.2017.110868
3. Lee, M.-T., Chang, H. T. (2011). On the pinned field image binarization for signature generation in image ownership verification method. EURASIP Journal on Advances in Signal Processing, 2011 (1). doi: https://doi.org/10.1186/1687-6180-2011-44
4. Wally, M., Faye, I., Ruhaya, D. (2015). Document Image Binarization Using Retinex and Global Thresholding. ELCVIA Electronic Letters on Computer Vision and Image Analysis, 14 (1). doi: https://doi.org/10.5565/rev/elcvia.648
5. Michalak, H., Okarma, K. (2019). Improvement of Image Binarization Methods Using Image Preprocessing with Local Entropy Filtering for Alphanumeric Character Recognition Purposes. Entropy, 21 (6), 562. doi: https://doi.org/10.3390/e21060562
6. Fedorov E., Utikina T., Lukashenko M., Chychuzhko M., Lukashenko V. (2019). A Method for Extracting a Breast Image from a Mammogram Based on Binarization, Sealing and Segmentation. CEUR Workshop Proceedings, 2488, 84–98. Available at: http://ceur-ws.org/Vol-2488/paper7.pdf
7. Koezi, A., Nikolov, N., Haluzynskyi, O., Burburska, S. (2019). Method of Threshold CT Image Segmentation of Skeletal Bones. Innovative Biosystems and Bioengineering, 3 (1), 4–11. doi: https://doi.org/10.26535/ibb.2019.3.154897
8. Meng, X., Gu, W., Chen, Y., Zhang, J. (2017). Brain MR image segmentation based on an improved active contour model. PLOS ONE, 12 (8), e0183943. doi: https://doi.org/10.1371/journal.pone.0183943
9. Pun, C.-M., An, N.-Y., Chen, C. L. P. (2012). Region-based Image Segmentation by Watershed Partition and DCT Energy Compaction. International Journal of Computational Intelligence Systems, 5 (1), 53–64. doi: https://doi.org/10.1080/18756891.2012.670521
10. Teodorescu, H., Rusu, M. (2012). Yet Another Method for Image Segmentation Based on Histograms and Heuristics. Computer Science Journal of Moldova, 20 (2 (59)), 163–177. Available at: http://www.math.md/files/esjsim/v20-n2/v20-n2-(pp163-177).pdf
11. Selvaraj Assley, P. S., Chellakkon, H. S. (2014). A Comparative Study on Medical Image Segmentation Methods. Applied Medical Informatics, 34 (1), 31–45. Available at: https://ami.info.umfcluj.ro/index.php/ami/article/view/460
12. Ren, Z. (2014). Variational Level Set Method for Two-Stage Image Segmentation Based on Morphological Gradients. Mathematical Problems in Engineering, 2014, 1–11. doi: https://doi.org/10.1155/2014/145343
13. Ganea, E., Burdescu, D. D., Brezovan, M. (2011). New Method to Detect Salient Objects in Image Segmentation using Hypergraph Structure. Advances in Electrical and Computer Engineering, 11 (4), 111–116. doi: https://doi.org/10.4316/acce.2011.04018
14. O’Mara, A., King, A. E., Vickers, J. C., Kirkcaldie, M. T. K. (2017). ImageSURF: An ImageJ Plugin for Batch Pixel-Based Image Segmentation Using Random Forests. Journal of Open Research Software, 5. doi: https://doi.org/10.5334/jors.172
15. Linyao, X., Jianguo, W. (2017). Improved K-means Algorithm Based on optimizing Initial Cluster Centers and Its Application. International Journal of Advanced Network, Monitoring and Controls, 2 (2), 9–16. doi: https://doi.org/10.21307/ijanmc-2017-095
16. Brusco, M. J., Shireman, E., Steinley, D. (2017). A comparison of latent class, K-means, and K-median methods for clustering dichotomous data. Psychological Methods, 22 (3), 563–580. doi: https://doi.org/10.1037/met0000095
17. Zhou, N., Yang, T., Zhang, S. (2014). An Improved FCM Medical Image Segmentation Algorithm Based on MMTD. Computational and Mathematical Methods in Medicine, 2014, 1–8. doi: https://doi.org/10.1155/2014/690349
18. Kesavaraja, D., Balasubramanian, R., Rajesh, R. S., Sasireka, D. (2011). Advanced Cluster Based Image Segmentation. ICTACT Journal on Image and Video Processing, 02 (02), 307–318. doi: https://doi.org/10.21917/ijivp.2011.0045
19. Fu, Z., Wang, L. (2012). Color Image Segmentation Using Gaussian Mixture Model and EM Algorithm. Advances in Electrical and Computer Engineering, 11 (4), 111–116. doi: https://doi.org/10.4316/acce.2011.04018
20. Giacoumidis, E., Lin, Y., Jarajreh, M., O'Duill, S., McGuinness, K., Whelan, P. F., Barry, L. P. (2019). A Blind Nonlinearity Compensator Using DBSCAN Clustering for Coherent Optical Transmission Systems. Applied Sciences, 9 (20), 4398. doi: https://doi.org/10.3390/app9204398
21. Olugbara, O. O., Adetiba, E., Oyewole, S. A. (2015). Pixel Intensity Clustering Algorithm for Multilevel Image Segmentation. Mathematical Problems in Engineering, 2015, 1–9. doi: https://doi.org/10.1155/2015/649802
22. Cahyono, C., Prasetyo, G., Yoya, A., Hani, R. (2014). Multithresholding in Grayscale Image Using Pea Finding Approach and Hierarchical Cluster Analysis. Jurnal Ilmu Komputer Dan Informasi, 7 (2), 83. doi: https://doi.org/10.21609/jiki.v7i2.261
23. Wang, X., Du, J., Wu, S., Li, X., Li, F. (2013). Cluster Ensemble-Based Image Segmentation. International Journal of Advanced Robotic Systems, 10 (7), 297. doi: https://doi.org/10.5772/36769
24. Ghahraman, B., Davary, K. (2014). Adopting Hierarchial Cluster Analysis to Improve the Performance of K-mean Algorithm. Journal of Water and Soil, 28 (3), 471–480. Available at: https://www.sid.ir/en/journal/ViewPaper.aspx?id=443469

25. Fedorov, E., Lukashenko, V., Utikina, T., Lukashenko, A., Rudakov, K. (2019). Method for Parametric Identification of Gaussian Mixture Model Based on Clonal Selection Algorithm. CEUR Workshop Proceedings, 2353, 41–55. Available at: http://ceur-ws.org/Vol-2353/paper4.pdf

26. Fedorov, E., Lukashenko, V., Patrushev, V., Lukashenko, A., Rudakov, K., Mitsenko, S. (2018). The Method of Intelligent Image Processing Based on a Three-Channel Purely Convolutional Neural. CEUR Workshop Proceedings, 2255, 336–351. Available at: http://ceur-ws.org/Vol-2255/paper30.pdf

27. Yu, C., Dai, F. (2016). Mobile Camera based Motion Segmentation by Image Resizing. Journal of Robotics, Networking and Artificial Life, 3 (2), 96. doi: https://doi.org/10.2991/jrnal.2016.3.2.7

28. Lemke, O., Keller, B. (2018). Common Nearest Neighbor Clustering – A Benchmark. Algorithms, 11 (2), 19. doi: https://doi.org/10.3390/a11020019

29. Xu, L., Yan, Y., Cheng, J. (2017). Guided Filtering For Solar Image/Video Processing. Solar-Terrestrial Physics, 3 (2), 9–15. doi: https://doi.org/10.12737/stp-3220172

30. Konsti, J., Lundin, M., Linder, N., Haglund, C., Blomqvist, C., Nevanlinna, H. et. al. (2012). Effect of image compression and scaling on automated scoring of immunohistochemical stainings and segmentation of tumor epithelium. Diagnostic Pathology, 7 (1). doi: https://doi.org/10.1186/1746-1596-7-29

31. Jeyaram, B. S., Raghavan, R. (2014). New CA Based Image Encryption-Scaling Scheme Using Wavelet Transform. Journal of Systems, Cybernetics and Informatics, 12 (3), 66–71. Available at: https://pdfs.semanticscholar.org/4d20/2d302da0e63a34570f34bdac3e43739d1.pdf?_ga=2.263733902.320808902.1581593117-1908018850.1550590803