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Combined use of Edge Selection Operators in Individual Color Channels for the Analysis of Cytological Images Presented in RGB Format

Asaad Babker[1]*, Rania Saad Suliman[2], Aisha Ali M Ghazwani[2], Wiam Al Harbi[3] and Vyacheslav Lyashenko[4]

[1]Department of Medical Laboratory Sciences, College of Health Sciences, Gulf Medical University, Ajman, UAE.
[2]Department of Clinical Laboratory Sciences, Prince Sultan Military College for Health Sciences, Dhahran, Saudi Arabia.
[3]Histopathology Department, King Fahad Military Medical Complex, Dhahran, Saudi Arabia.
[4]Department of Media Systems and Technology, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine.
*Corresponding Author E-mail: azad.88@hotmail.com

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Digital medical images study, analysis and processing is one of medical visualization areas, which helps to improve diagnostic diseases and detection, monitoring their progression and treatment. In this regard, the analysis of cytological images is important and effective, it allows to study various cellular structures. One of the components of such research is the allocation of potential areas of interest, considering the specifics of color medical images presentation. The paper proposes a new combined approach for identifying potential areas of interest based on edge detection operators, which is compared with the corresponding classical methods. It is shown that the proposed combined approach gives results no worse than classical methods, and for some types of images, even better. At the same time, resulting images quality assessments compactness is achieved, the range of the obtained results for making effective decisions is expanded depending on the specification of the analysis goals. It is shown that for images with a semi-transparent background, low-contrast difference between the background and objects of interest the proposed approach, in comparison with classical approaches, provides superiority in terms of niqe quality assessment of at least 10%, brisque quality assessment of more than 20%, derivative assessments (ME and AE) – 7.5% and 1%, respectively. The analysis of potential areas of interest details based on the processed images visualization results is the best for the combined approach in all cases. At the same time, the study provides an answer to the best combination of edge detection operators in individual color channels and without using pre-processing methods of the original image. This allows for increased efficiency of clinical trials in making a diagnosis.

Keywords: Color Channels, Cytological Image, Edge Detection, Image Processing, Medical Image, Microscopic Smear, RGB Format.

Cytological images are one of information sources for decision-making in medical practice for the diseases and diagnosis detection, monitoring the disease progress and its treatment.[1-4] Among cytological images, images of various cells should be highlighted, including blood cells, which are used for primary diagnosis or more detailed examination of a certain disease.[5,6] Thus, the analysis of cytological images is constantly in the field of view of researchers and doctors.

Cytological images are mainly microscopic images presented in color. Various methods of staining microscopic smears are used for these purposes.[7,8] Each method has its own specifics, purposes for staining and disadvantages. A common disadvantage of staining is the uneven distribution of the dye in the smear and, as a result, insufficient staining of certain objects for their accurate identification.[9,10] Ultimately, this affects the solution of various problems of studying microscopic smears, the precise selection of objects of study. Therefore, the task of improving the analysis quality for the necessary objects of interest selection arises.

The most common format for digital representation of cytological images is the RGB format.[4, 11, 12] RGB format – Red, Green, and Blue (A type of color space for representing color images). For the purposes of analysis, various methods and approaches to digital image processing are used.[13-17] Among such methods, edge detection should be highlighted. This can be used for segmentation, identification and determination of potential areas of interest. For example, a study considers issues of improving edge detection in cytological images of the cervix.[18] The authors emphasize the need to color the smear under study and the complexity of automatic detection of cell nuclei. Such complexity, as the researchers of the article claim, is associated with uneven coloring of all samples and, consequently, a decrease in the accuracy of cell nuclei detection. For the purposes of the study, the authors consider a whole classifier system that allows dividing cells into aberrant and normal, based on the available data. Chen et al[19] reviews approaches to segmentation of overlapping cells in cervical cytology images, which also considers edge detection methods. The authors emphasize the importance of the staining of the smear being examined, but at the same time draw attention to the fact that in conditions of overlapping cells, uneven staining distribution across the smear complicates clear detection of the cell edge and subsequent segmentation procedure. The paper shows that traditional machine learning methods and deep learning methods can be used for research purposes. This emphasizes the complexity and versatility of the possible solution to the problem posed. The paper considers a diagnostic system for detecting cancer cells in cytological images of pleural effusion.[20] The basis of such a system is the edge detection methods. It is important to have an automated system for screening cytological images. However, such systems face the disadvantages of smear staining. Therefore, to improve the accuracy of detecting the necessary areas of interest, the authors use several morphological operations to clarify the initial results. Merlina et al[21] analyze the efficiency of using preliminary processing methods to detect cell boundaries in images of smears of cytological preparations. The authors note that the complexity of the cell structure, their possible overlapping and uneven distribution of the staining preparation lead to poor image contrast. This affects the efficiency of edge detection and complicates automatic visual interpretation of the presented data. To solve this problem, the authors explore the possibility of using edge detection operators such as Robert's and Prewitt's. Article studies the issues of pixel segmentation of cytological images, where edge detection methods are also considered.[22]

An interesting approach is described in the work of Alquran et al.,[23] which is based on the use of image channel transformation methods. For these purposes, the authors consider individual color channels of the RGB and HSV representation of the original image, which are used for such analysis. In this case, the authors select the channels with the best results. However, this approach does not significantly eliminate the inefficiency of staining the smear under study. In this case, it is advisable to consider all channels in each individual digital representation format of the input image. And then obtain the resulting image considering the data on individual channels for each digital image representation format. At the same time, different edge detection operators can be used in each color channel, which should increase the overall efficiency of detecting potential areas of interest.

Thus, the key objective of this work is to investigate the combined use of edge detection operators in individual color channels for the analysis of cytological images presented in RGB format.

MATERIALS AND METHODS

General methodology for conducting the study and examples of cytological images for analysis

To achieve the goal of this study, it is necessary to consider various edge detection options for color cytological images. Here it is advisable to highlight:

The classical approach, which involves preliminary conversion of a color image from RGB format to monochrome format (or gray format) with subsequent edge detection by some operator and superimposition of the results on the input image.

This approach, which involves decomposing a color image in RGB format into separate color channels with subsequent processing by the same edge detection operator, merging the obtained results and superimposing them on the input image. This is the so-called improved classical approach.

The combined use of different edge detection operators in separate color channels, merging the obtained results and generalizing them on the input image.

Next, the obtained results are compared using a certain set of quality assessments of the processed images and the obtained results are generalized.

The general scheme of such a study is presented in Fig 1.

At the same time, the corresponding formalization of the approach under consideration is presented as follows:

1. For the classical approach

$$B_{RGB} \rightarrow B_{gray} \xrightarrow[\{EDGE\}]{} B_{edge} \rightarrow (B_{RGB} \cap B_{edge}) \xrightarrow[\{QA\}]{} R_C(QA), \quad ...(1)$$

where

B_{RGB} – original input color cytology image,

B_{gray} – converted image in gray format,

$\{EDGE\}$ – a set of edge extraction operators that are used in the study,

B_{edge} – processed image after applying the edge selection operator,

$B_{RGB} \cap B_{edge}$ – overlay image of edge extraction results and input image,

$\{QA\}$ – evaluations of the resulting image quality,

$R_C(QA)$ – a set of quality scores for comparison for the classical approach.

2. For an improved classical approach

$$B_{RGB} \rightarrow \begin{cases} B_R \\ B_G \\ B_B \end{cases} \xrightarrow[\{EDGE\}]{} \begin{cases} B_{R_{edge}} \\ B_{G_{edge}} (Edge_R = Edge_G = Edge_B) \rightarrow \\ B_{B_{edge}} \end{cases}$$

$$\rightarrow (B_{R_{edge}} \cap B_{G_{edge}} \cap B_{B_{edge}}) \rightarrow (B_{RGB} \cap B_{edge}) \xrightarrow[\{QA\}]{} R_{IC}(QA), \quad ...(2)$$

where

B_R, B_G, B_B – decomposition of the original input image B_{RGB} into separate color channels R, G, B,

$B_{R_{edge}}, B_{G_{edge}}, B_{B_{edge}}$ – edge selection results in individual color channels. Here the edge selection operator is the same for each color channel $Edge_R = Edge_G = Edge_B$, $B_{R_{edge}} \cap B_{G_{edge}} \cap B_{B_{edge}}$ – merging the edge selection results in each channel into a single image,

$R_{IC}(QA)$ – a set of quality scores for comparison for the improved classical approach.

3. For the combined use of edge detection operators

$$B_{RGB} \rightarrow \begin{cases} B_R \\ B_G \\ B_B \end{cases} \xrightarrow[\{EDGE\}]{} \begin{cases} B_{R_{edge}} \\ B_{G_{edge}} (Edge_R \neq Edge_G \neq Edge_B) \rightarrow \\ B_{B_{edge}} \end{cases}$$

$$\rightarrow (B_{R_{edge}} \cap B_{G_{edge}} \cap B_{B_{edge}}) \rightarrow (B_{RGB} \cap B_{edge}) \xrightarrow[\{QA\}]{} R_{IC}(QA), \quad ...(3)$$

Thus, the essence of the corresponding study in this article is carried out according to the presented in Fig. 1 and on the basis of the formalization presented above. For these purposes, various examples of cytological images are considered, which are presented below. All images are in the public domain and were used in our earlier work.

Each figure, which will be referred to hereafter as Example 1, Example 2 and Example 3, shows cytological images and their corresponding brightness distribution histogram.

It should be noted that all images in Fig. 2a, Fig. 3a and Fig. 4a differ from each other. These images have different data formation textures, color gamut of the studied details representation, visualization contrast, and difference in brightness between the background and objects of interest.

The difference in the presented samples of microscopic cytological smears is emphasized by the histograms of the brightness distribution, which can be seen from Fig. 2b, Fig. 3b and Fig. 4b. All this emphasizes the complexity of solving the task at hand, which must be performed automatically. At the same time, it is necessary to talk about the typicality of such images, which allows us to generalize the results obtained. In this case, it is important not so much to determine the contours of the cells, as to highlight potential areas of interest, which are various elements of such cells.

Edge detection and image quality assessment methods used in the study

A prerequisite for conducting this study is a specific set of edge detection operators selection. Among such operators, the most popular are classic edge detection detectors.[24,25] Among such detectors, the following are usually considered: Prewitt, Roberts, Sobel, LoG and Canny operators.[26, 27] Each of the edge detection operators has its own characteristics and disadvantages. However, the most common for processing digital microscopic medical images are Sobel, LoG and Prewitt operators.[28,29] This choice takes into account the medical images formation and presentation conditions, and their visualization features.

So, the Sobel edge detection operator is based on convolution of the image with small separable integer filters in the vertical and horizontal directions.[30] The Sobel operator allows finding the direction of the greatest increase in brightness and the magnitude of its change in this direction at each point in the image.[31,32] It is easy to use and easy to calculate, which expands the possibilities of application and obtaining reliable results.

The LoG operator is calculated as the sum of the differences on the neighbors of the central pixel.[33,34] At the same time, the LoG operator allows for significant detailing of both small details and wider edge transitions. This makes it indispensable in the study of microscopic medical images, which include cytological images.

The Prewitt operator finds the local orientation of the edge at each pixel.[35,36] This operator was specifically designed for edge detection in medical images.

Thus, the edge detection operators used for the analysis in this study are Sobel, LoG, and Prewitt.

No less important, but problematic is the issue of choosing the quality assessments of the resulting images, which is confirmed by many relevant studies.[37-40] This is due to both the multitude of such assessments and the issue of choosing such assessments in a particular case, which is determined by the task being solved. Since this study conducts a comparative analysis of the quality of areas of interest selection, it seems appropriate to choose no-reference quality assessments. This is because in this case it is difficult to determine the reference model with which the necessary comparison will be made. Moreover, the choice of such a model is subjective.

Based on the above, the most popular no-reference quality assessments are: niqe and brisque.[41-43] These assessments allow us to evaluate

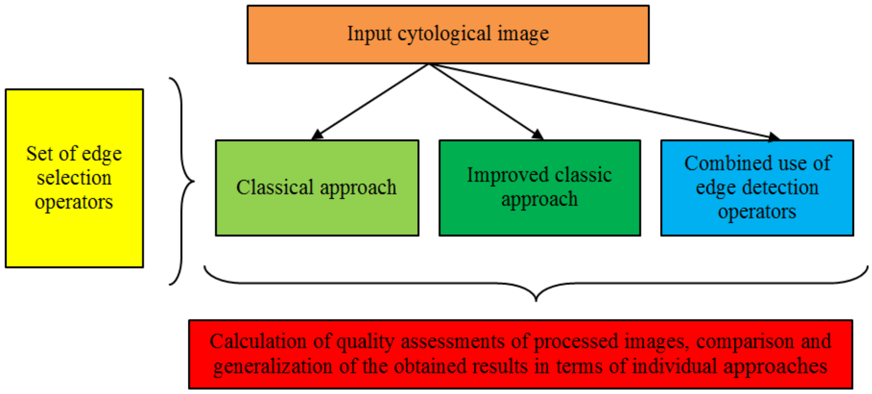


Fig. 1. Generalized scheme for conducting a comparative analysis in a study using individual edge detection operators on cytological images

the quality of naturalness and spatial quality of the image under study, respectively. Lower values of such assessments indicate a better quality of the resulting image perception, which is important in medical visualization. At the same time, these assessments allow us to talk about the possibility of considering derivative assessments. This is important if the assessments have a significant spread in indicators relative to each other.

In the first case, we should consider the multiplication of such estimates *ME*:

$$ME = n \times b \quad ...(4)$$

where

n – niqe assessment,

b – brisque assessment.

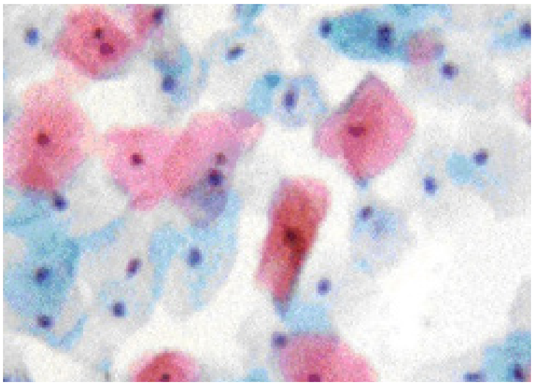
In the second case, additivity *AE*:

$$AE = n + b \quad ...(5)$$

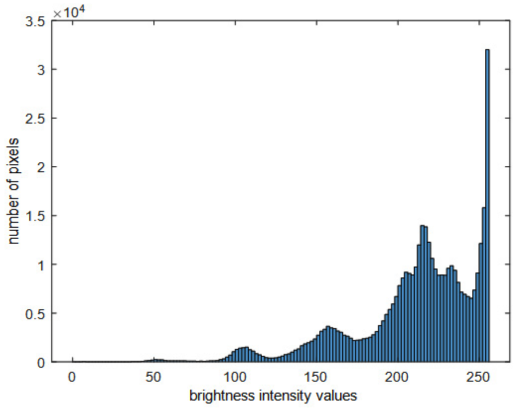
If necessary, for the purpose of efficient data visualization, the normalized niqe and brisque estimates (estimates that are brought to a common measurement scale for comparison purposes) can be considered when considering the multiplication and additivity of such estimates.

RESULTS

Considering the results obtained during the processing of the cytological images studied by various edge detection operators, we will first pay attention to the classical approach effectiveness and the improved classical approach. Table 1 presents

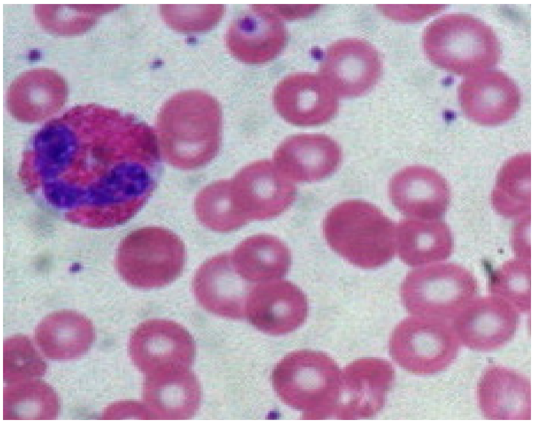


a). Original image

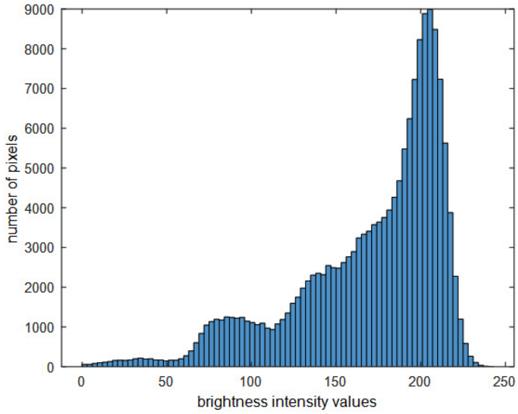


b). Brightness distribution histogram

Fig. 2. Cytology image as a representation of the multifaceted presentation of color medical imaging – Example 1



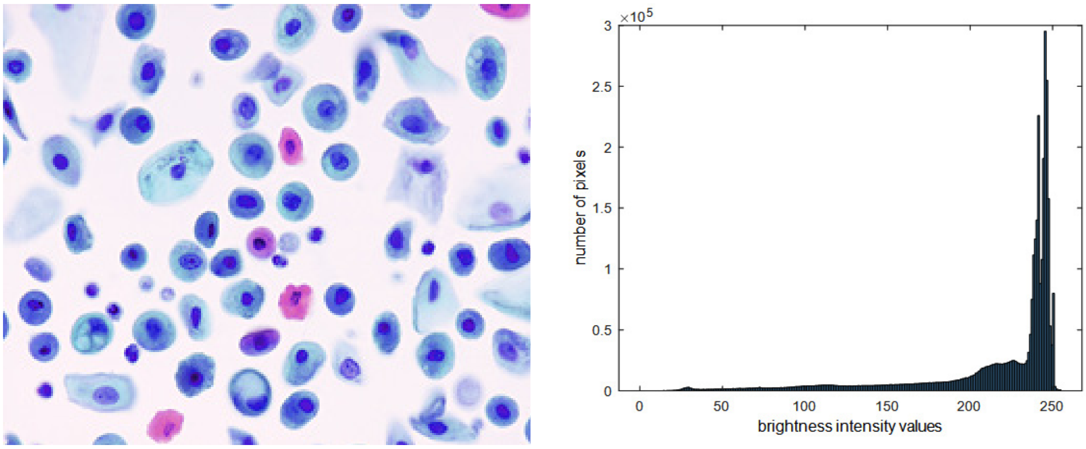
a). Original image



b). Brightness distribution histogram

Fig. 3. Cytology image as a representation of the multifaceted presentation of color medical imaging – Example 2

the results of edge detection by various operators based on the images processing, considered Example 1, Example 2 and Example 3. Such results are presented in the form of individual indicators values for assessing the resulting images quality.



a). Original image

b). Brightness distribution histogram

Fig. 4. Cytology image as a representation of the multifaceted presentation of color medical imaging – Example 3

Table 1. The resulting images quality assessments after their processing by different edge detection operators (case of classical and improved classical approaches)

Edge highlight operator	Quality assessments/classical approach				Quality assessments/improved classical approach			
	niqe	brisque	ME	AE	niqe	brisque	ME	AE
Image – Example 1								
Sobel	25.7389	53.4262	1375.1316	79.1651	28.4477	53.3857	1518.7003	81.8334
LoG	27.4630	43.4610	1193.5694	70.9240	21.9946	43.4583	955.8457	65.4528
Prewitt	25.6791	52.9653	1360.1012	78.6444	27.3835	53.1094	1454.3212	80.4929
Image – Example 2								
Sobel	26.6862	54.8421	1463.5272	81.5283	31.8181	54.4291	1731.8305	86.2472
LoG	35.0309	49.0205	1717.2322	84.0514	39.0471	43.4659	1697.2173	82.513
Prewitt	27.3443	54.8270	1499.2059	82.1713	31.9586	54.2728	1734.4827	86.2314
Image – Example 3								
Sobel	20.9890	47.2352	991.4196	68.2242	17.3445	49.9855	866.9735	67,33
LoG	21.8886	52.0877	1140.126	73.9763	15.8190	47.0056	743.5815	62.8246
Prewitt	20.9404	47.1556	987.4571	68.096	18.3299	49.9631	915.8186	68.293

Table 2. Processed image Example 1 quality assessments after combined processing with different edge detection operators in different color channels

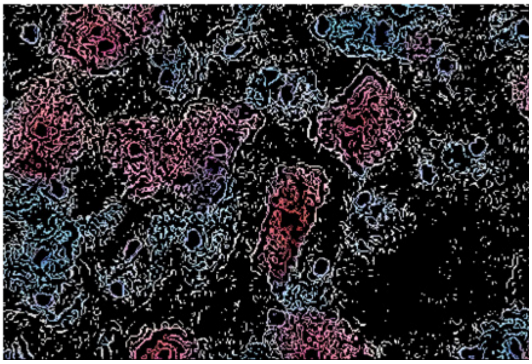
Combined edge selection operator	Quality assessments			
	niqe	brisque	ME	AE
SLP	22.3574	43.7738	978.6683	66.1312
SPL	22.6336	**43.4583**	983.6177	66.0919
LSP	22.2815	43.7063	973.8419	65.9878
LPS	22.4599	43.7098	981.7177	66.1697
PSL	22.8204	43.4584	991,7380	66.2788
PLS	**20.2594**	43.7983	**887.3272**	**64.0577**

Here and below, the most significant assessments are highlighted in bold and underlined font.

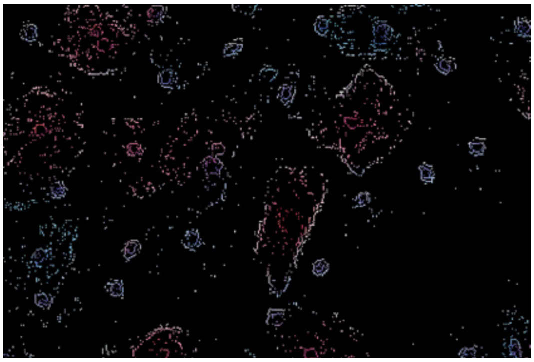
It should be noted that for each image, its own assessment types prevail in each specific case of using edge detection operators. This emphasizes the differences in the presented images, their complexity and the uniqueness of conducting the corresponding analysis. The greatest unity in the presented assessments is observed in terms of derived assessments (ME and AE).

It should also be noted that the Prewitt operator, as a specialized edge detection operator for medical images, does not always give the best result.

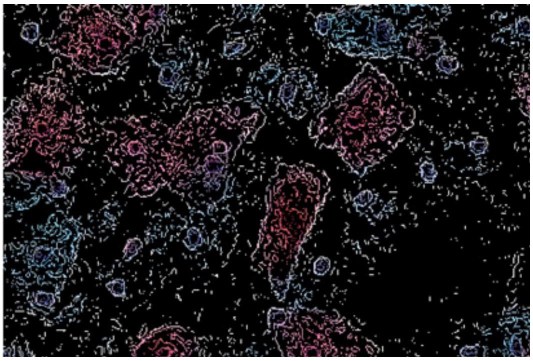
Table 2 presents the edge detection operators combined use results for the image Example 1 (Fig. 2a). This cytological image



a). Improved processing by LoG operator



b). Classical processing by the Prewitt operator



c). Combined processing approach – PLS

Fig. 5. The result of image processing Example 1 using different approaches as a result of reflecting the superiority of the combined approach

Table 3. Processed image Example 2 quality assessments after combined processing with different edge detection operators in different color channels

Combined edge selection operator	Quality assessments niqe	brisque	ME	AE
SLP	37.0737	51.5409	1910.8118	88.6146
SPL	**<u>36.6371</u>**	49.6971	**<u>1820.7576</u>**	86.3342
LSP	43.6763	43.5209	1900.8318	87.1972
LPS	42.6602	**<u>43.4167</u>**	1852.1651	**<u>86.0769</u>**
PSL	37.8903	49.3671	1870.5342	87.2574
PLS	37.4086	51.2971	1918.9526	88.7057

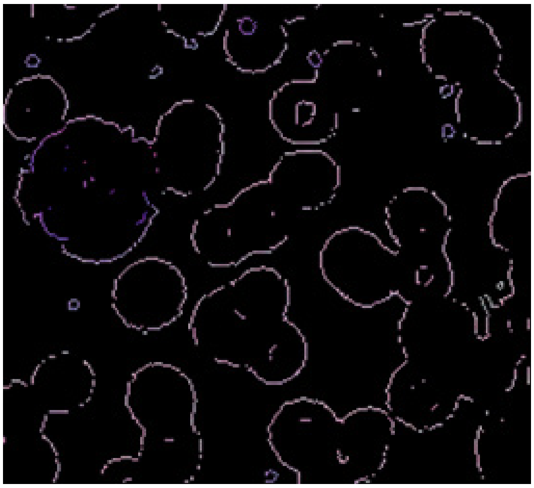
is characterized by the fact that some cellular structures are translucent and some of them are slightly visible against the background. This generally complicates the edge detection and potential areas of interest identification process.

From here on, the abbreviation for the combined edge selection operator means in the first place is the first letter of the edge operator Sobel (S), LoG (L) or Prewitt (P) for the R color channel, in the second place is for the G color channel, and in the third place is B, for the original image presented in RGB format.

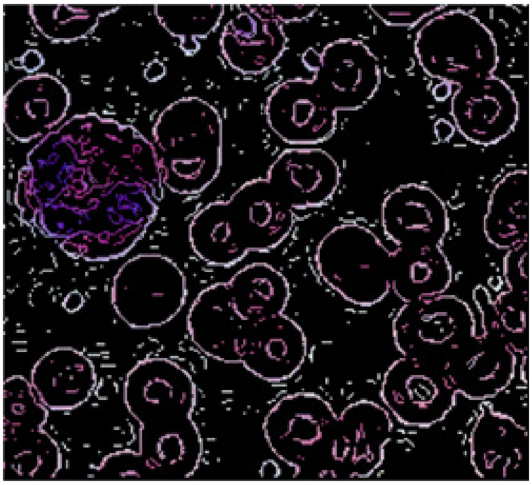
As can be seen from the data in Table 2, the most effective combined form of original image Example 1 processing is the combination – PLS (channel R – operator Prewitt, channel G – operator LoG, channel B – operator Sobel).

When comparing the data in Table 2 and the corresponding data in Table 1, it should be emphasized:

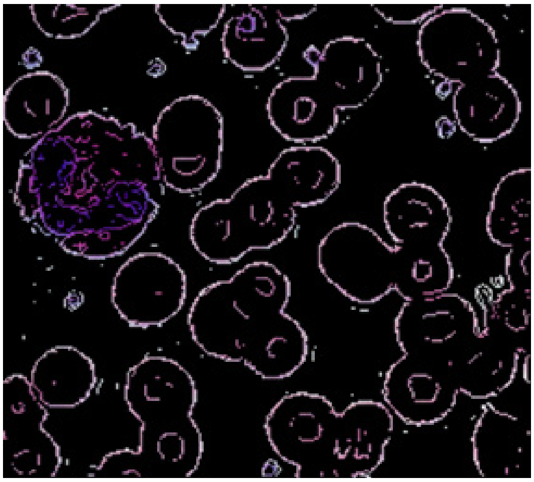
– in terms of niqe quality assessment, the combined approach to image processing Example 1 exceeds the corresponding indicators in both the classical



a). Classical approach using the Sobel operator



b). An improved classical approach based on the LoG operator



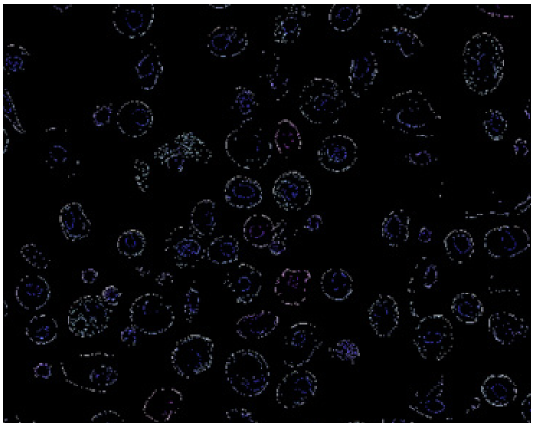
c). Combined processing approach –SPL

Fig. 6. The result of image processing Example 2 using different approaches as a result of reflecting the superiority of the combined approach

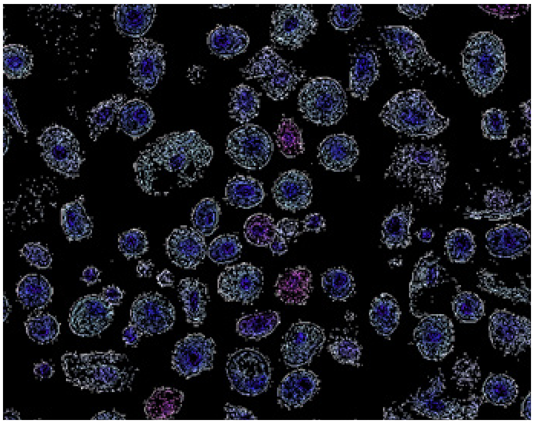
and improved classical approaches. This superiority is at least 10%,
– in terms of brisque quality assessment, the combined approach to image processing Example 1 is no worse than the data from the classical and improved classical approaches. Moreover, in the combined approach, the brisque quality assessment is approximately at the same level for various combinations of edge detection operators for different color channels. In general, this allows

Table 4. Processed image Example 3 quality assessments after combined processing with different edge detection operators in different color channels

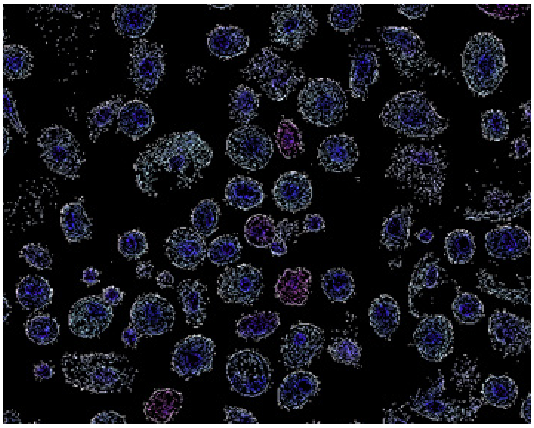
Combined edge selection operator	niqe	Quality assessments brisque	ME	AE
SLP	15.6629	49.7585	779,3624	65,4214
SPL	**15.5564**	**49.5637**	**771,0327**	**65,1201**
LSP	15.8833	49.9519	793,4010	65,8352
LPS	15.8744	49.9082	792,2627	65,7826
PSL	15.5710	49.5588	771,6800	65,1298
PLS	15.6143	49.6973	775,9885	65,3116



a). Classical approach using the Prewitt operator

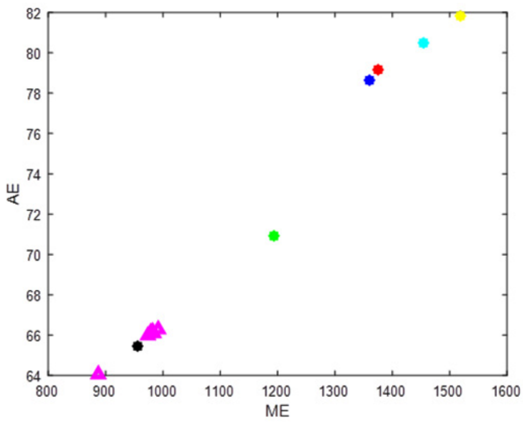


b). An improved classical approach based on the LoG operator

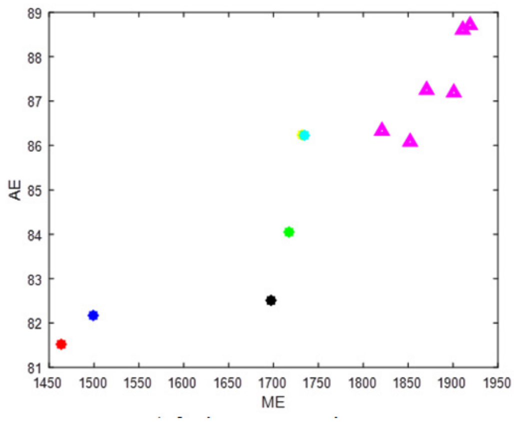


c). Combined processing approach –SPL

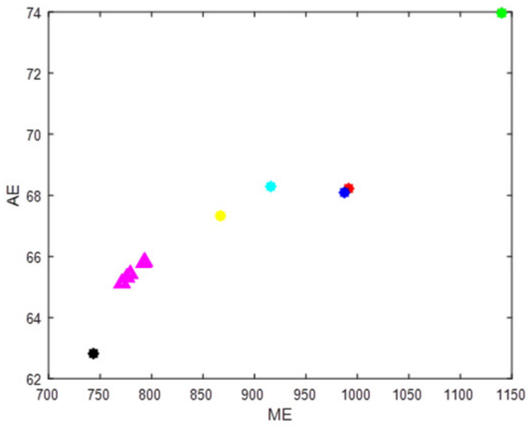
Fig. 7. The result of image processing Example 3 using different approaches as a result of reflecting the superiority of the combined approach



a). For image Example 1



b). For image Example 2



c). For image Example 3

Fig. 8. Individual images processing results using different approaches, summarized based on ME and AE estimates

us to talk about the effectiveness of the combined approach in terms of brisque assessment in comparison with the data in Table 1, by more than 20%. This increases this cytological images type processing efficiency by the combined approach for identifying areas of interest,

– according to the derivative estimates (ME and AE), it is also worth noting the superiority of the combined approach to identifying potential areas of interest based on edge detection operators in comparison with the classical and improved classical approaches. The minimum value of such superiority is 7.5% for the ME estimate and 1% for the AE estimate. It should also be noted here that there are minor fluctuations in the derived estimates (ME and AE) for the combined approach, which cannot be said about the data for the classical and improved approaches.

No less important is the visual examination of the results obtained. Figure 5 shows some results of the corresponding image processing Example 1.

From the data in Fig. 5 it is evident that processing the original image Example 1 with the improved classical approach using the LoG operator gives good detailing of the areas of interest. However, many false points appear, which complicates further processing of such an image.

The original image Example 1 processing using the classical approach based on the Prewitt operator does not provide sufficient detail; many potential areas of interest are missed, which necessitates original image additional processing.

Processing the original image Example 1 with a combined approach based on the PLS combination yields good detailing. At the same time, the number of false points is significantly smaller than in the case of processing with an improved classical approach using the LoG operator. Moreover, such false points can be eliminated using simple filtering methods. This is more difficult to do than the image shown in Fig. 5a.

In general, the presented results for the image Example 1 are acceptable, given the complexity of this image. Moreover, our main task is to show the possibility and feasibility of using the proposed combined approach to processing cytological images without any preliminary processing of the input image.

Table 3 shows the edge detection operators combined use results for the image Example 2 (Fig. 3a). This image has a significant difference between the color and contrast of the background and potential areas of interest. In addition, small details in the form of platelets and places where false highlights are observed in the background should be noted in the image. All of that can complicate the corresponding process and affect the result.

When examining the data in Table 3 in comparison with the corresponding data in Table 1, it should be noted:

– all the considered values estimates are more compact for the proposed combined approach in comparison with such estimates for the classical and improved classical approaches,

– niqe estimates in the classical and improved approaches are less than niqe estimates for the combined approach. The opposite is also observed for some positions,

– brisque estimates in the combined approach are generally better in comparison with brisque estimates for the classical and improved classical approaches,

– the values of the derived estimates (ME and AE) for the classical and improved classical approaches are also less than the corresponding values of the estimates for the combined approach.

Considering the above, we will conduct a the best results visual comparison in each of the approaches under consideration (Fig. 6).

The data in Fig. 6a show that the use of the classical approach based on the Sobel edge extraction operator in this case does not sufficiently detail the possible areas of interest. This concerns the cell nuclei and the structure of the megaloblastic anemia cell. At the same time, small details such as platelets are highlighted.

Using an improved classical approach based on the LoG edge detection operator gives good detailing of all features of potential areas of interest (Fig. 6b). However, false highlights present in the background are also identified. This adds many false points. Ultimately, all this complicates the overall procedure of identifying areas of interest.

The use of a combined approach based on its SPL variety allows for good detailing of potential areas of interest (Fig. 6c). At the same time, false points are almost absent.

Considering that for the image Example 2 the corresponding quality assessments are contradictory, one should rely on the obtained results visualization. Thus, the combined approach considered also shows a good result in this case. At the same time, to improve the proposed approach, attention should be paid to the selection of the resulting image more effective estimates. For example, for these purposes, the opinions of experts can be considered. Nevertheless, in any case, the proposed combined approach expands the base for research and gives practicing doctors the opportunity to choose the best presentation of the original images processing results.

Table 4 shows the edge detection operators combined use results for the image Example 3 (Fig. 4a). This image has different areas: with a clear separation of the background and objects of interest, individual objects complex detailing, minor differences in color and contrasts between objects and the background. All of that imposes its own peculiarities on this image analysis.

The data in Table 4 analysis shows that

– the niqe evaluation values for the combined approach are the best in all cases of such consideration in comparison with the classical and improved classical approaches. Also, in general, the niqe evaluation values for the combined approach are more compact,

– the values of the brisque estimates for the combined approach are also more compact in comparison with the classical and improved classical approaches. In general, such estimates for the combined approach are not worse than the estimates for the classical and improved classical approaches. It can be seen that such estimates values are in the middle of estimates values set for the classical and improved classical approaches,

– the derived estimates (ME and AE) are multifaceted. Thus, in comparison with the classical approach, the ME estimates for the combined approach are better. This should also be said regarding the values of the AE estimates. In comparison with the improved classical approach, the ME estimates for the combined approach are inthe former values middle. The same is also characteristic of the AE estimates.

Thus, positive results are also observed here for the combined approach compared to the classical and improved classical approaches for the purpose of identifying potential regions of interest based on edge detection operators.

Fig. 7 shows the results of the best extraction of areas of potential interest for the image Example 3 based on different approaches used for its processing.

The data in Fig. 7a show insufficiently complete selection of all potential areas of interest. This concerns those cells whose color merges with the background color and is low contrast. The detailing of individual cellular structures is also insufficient.

Better detailing of potential areas of interest is observed based on the data in Fig. 7b and Fig. 7c. Here, cells whose color merge with the background color and are low-contrast are more clearly drawn. Various cellular structures are also better visible. At first glance, the data in Fig. 7b and Fig. 7c seem identical, but this is not so. In Fig. 7c, compared to Fig. 7b, cellular structures with an edge effect are better drawn. This is visible at the bottom of each Fig. 7b and Fig. 7c when comparing them. Such edge effects are sometimes useful for analysis, since they necessitate additional studies.

Thus, overall, the combined approach also shows good results for the image Example 3.

At the end of the obtained results review, we will briefly dwell on the importance of considering the quality assessment generalized indicators. First, the compactness of their values is striking, which indicates the combined approach considered effectiveness (see Fig. 8 for the different images presented).

The nest is shown here: magenta triangular marks – generalized quality estimates of ME and AE when processing images using the combined approach; a red circle mark (operator Sobel), green (operator LoG), blue (operator Prewitt) are used when processing images using the classical approach; a yellow circle mark (operator Sobel), black (operator LoG), cyan (operator Prewitt) are used when processing images using the improved classical approach.

It is evident from the data in Fig. 8 that the ME and AE assessments results are compact precisely for the combined approach in comparison with the classical and improved classical approaches. The disadvantages are the fact that such assessments do not always fully reflect the dynamics of comparison by means of primary assessments (niqe and brisque), which was mentioned when considering the data on assessments in separate tables above. Also, the generalized assessment should include obtained results visualization assessments, which will allow making more balanced decisions. In this case, detailing the areas of potential interest under consideration is important. Nevertheless, this does not reduce the overall assessment of the proposed combined approach and the feasibility of its practical use. The noted shortcomings can be the basis for further research.

It should also be noted that the combined approach generally prevails. However, each specific case has its own most effective combination of image processing. Most likely, this is due to the difference in the efficiency of using individual edge selection operators and the unevenness of the color of the smears, which is reflected in the presentation of the overall color in the form of individual color channels. This necessitates additional research to examine in detail the potential limitations of the combined approach in specific scenarios and propose options to overcome them. The general concept of the combined approach is also considered here, and the feasibility of its application is substantiated.

DISCUSSION

Medical information using digital images presentation and study is one of the powerful tools for diagnosing diseases, determining ways for their treatment and monitoring such processes.[44-48] Each specific case uses a specific type of medical images and information, which creates the need to address individual specific issues. Thus, there is a need to use different methods of processing and analyzing the relevant information.[49-52] This explains the growing interest in the field of such research and the emergence of many different scientific and practical works. Among such studies, a special place is occupied by works that consider methods and approaches to the analysis of cytological images.

In their work, Alias et al[18] focus on preliminary procedures for improving the input image quality. In particular, the authors propose using contrast enhancement to improve edge detection efficiency for the purpose of identifying the nuclei of the cells under study. This allowed us to state that this approach improves the detection of cell nuclei by 6.15% compared to similar studies and reaches 90% in the case of identifying cells among seven classes.[18] Our study is different in that it does not consider preliminary procedures for improving the input image but investigates the feasibility of using a new approach to highlight potential areas of interest in the original input images. In addition, our work contains comparative studies of the proposed approach with classical approaches. It is shown that the efficiency of the approach proposed in our work ranges from 1 to 20% compared to classical methods and depends on the features of the image being processed.

Win et al[20] also use input image preprocessing methods in their study of cytological images. These methods include brightness intensity adjustment and median filtering to improve the quality of the original image. Edge detection and edge correction methods were used to extract cell nuclei. This highlights the importance of analyzing different approaches used for edge detection. The authors of the study achieved 98.7% cell identification accuracy and the sensitivity of the method was 87.97.[20] The work pays special attention to images with overlapping cells. In this regard, this position echoes our studies, which contain translucent images of cells and their similarity to the surrounding background. In their work, the authors emphasize the effectiveness of the proposed hybrid approach, which also echoes our ideas on the use of a combined approach for edge detection.[20]

The study by KT et al[53] provides a detailed review of the methods and approaches for analyzing images of red blood cells, their extraction and identification. The need to automate this process is emphasized, which determines the feasibility of developing new methods using image processing. This is completely consistent with the main ideas of our study, its main goal. The authors of another study also note the importance of considering edge detection methods as a basis for analyzing images of red blood cells.[53] The work emphasizes the use of hybrid methods for analyzing images of red blood cells as a type of cytological image. This makes the above-mentioned combined approach to edge detection appropriate for identifying potential areas of interest. The work emphasizes that previously developed approaches had good characteristics of the accuracy of identifying individual cellular structures in a blood smear, at least 90%.[53] However, with the transition to processing color images and the use of different methods of their coloring, there is a need to use new approaches to carry out the appropriate analysis.

The work of Di Ruberto et al[54] is devoted to the detection of red and white blood cells from microscopic images of blood. For this purpose, a new combined approach for the detection and quantification of individual blood cells is proposed, where special attention is also paid to edge detection methods. For the malaria parasite database, the accuracy in the range of 89–99% was achieved.[54] However, for the erythrocyte database, the detection accuracy fluctuates in the range of 96–98% for 180 images.[53] Thus, the relative comparison of the results obtained in different works is not always objective. This is due to the fact that such accuracy depends on the type of processed images. In this regard, our study provides a comparison of the classical approach and the proposed combined approach on the same images. This increases the overall assessment of the results obtained.

Das et al[55] analyze blood cells using different edge extraction operators. The paper considers such elements of cellular structures as nuclei and cytoplasm. For the purposes of analysis, edge extraction operators such as Canny, Sobel, and Laplacian of a Gaussian are considered in comparison with the approach proposed by the authors. The authors achieved 85% accuracy for identifying different cell types.[55] This is fully consistent with the results presented above.

Al-Hafiz et al[56] consider the issues of erythrocyte segmentation using a threshold value and a Canny detector. First of all, the authors emphasize that automation of the erythrocyte segmentation process remains a complex task, which gives rise to the development of new methods and approaches to its solution. For these purposes, the authors propose to initially use a number of improvements in local and global details of the input data based on morphological operations. Next, the Canny edge detection operator is used. In general, this approach provides an accuracy of 87.9%.[56] This is also consistent with the results obtained and described above. Moreover, it can be said that the classical use of edge detection operators does not always give the optimal result, which is confirmed in study.[56] At the same time, as noted in article,[53] the analysis of medical cytological images, where predominantly classical approaches based on traditional edge detection methods are used, does not exceed 5% of the total number of such studies. This gives rise to the development of new modified algorithms for edge detection in medical images.

Merlina et al[21] pay special attention to the methods of pre-processing the original image for more efficient edge detection in medical images. In this study, the efficiency of edge detection using the Robert and Prewitt operators is considered. A specific method of staining the studied smears, which gives poor contrast, is also considered.[21] Thus, the authors know in advance the necessity of using the methods of pre-processing the original image. But this cannot always be known, especially when automating the relevant processes. The result of the accuracy of detection of the necessary cells and their nuclei, which was obtained in the work,[21] is 86.8%. At the same time, it is not clear to which edge detection method this result refers. In our study, individual edge detection methods and characteristics of the results obtained in each case are clearly distinguished.

Alquran et al[23] also explore the possibility of the cell nuclei identification efficiency increasing in a smear based on digital image analysis. Here, different color channels are also allocated for subsequent analysis. However, such allocation does not imply different edge detection methods combined use. In fact, the authors use individual channels as the original image representation modification in gray format. In this case, the accuracy of 88.3% is achieved.[23] At the same time, the work emphasizes that the disadvantage of representing color digital medical images is poor contrast and uneven coloring.[23] Yes, any color channel can give a better result, but other channels can provide additional information and increase the detection accuracy. For these purposes, it is important to use the individual channels results combination. This is what the approach described in our study suggests.

The above confirms that the topic under consideration is in demand and corresponds to the key provisions of the analysis in the field of color cytological image processing for decision making. At the same time, many provisions are confirmed by the corresponding conclusions of other authors and substantiate the feasibility of further research in this area.

CONCLUSION

This paper presents a new combined approach to using edge detection operators in individual color channels for analyzing cytological images presented in RGB format. This approach is compared with classical and improved classical approaches for detecting potential areas of interest in cytological images. For these purposes, color cytological images of varying complexity and edge detection operators such as Sobel, LoG, and Prewitt are considered. To evaluate the results, niqe and brisque scores, as well as their multiplicative (ME) and additive (AE) combinations, are used.

The proposed combined approach strength is the possibility to obtain a set of original image processing results, possessing the property of their results estimates compactness in comparison with classical approaches. This expands the possibility of research choice for doctors, since in many cases the combined approach gives better values of estimates. The problematic aspect of the proposed combined approach is the need to improve the derivative estimates of the processing results (ME and AE), since in some cases such estimates are not the best in comparison with simple estimates (niqe and brisque).

A number of experiments were conducted, the results of which are presented in the form of a different assessments set, which is effective for conducting a comparative analysis. Also, the processing results are visualized in the form of different images for some approaches that were applied to processing the original images. This allows us to draw conclusions regarding the quality assessments used for the processing results obtained.

The main direction of these studies continuation is to consider the improvement of derivative estimates for the comparing the obtained results purposes. It is also important to expand such studies: study of possible ways of combining intermediate results in each channel into a single whole, study of contrasting to increase the efficiency of identifying potential areas of interest. A separate topic of research is a detailed study of the potential limitations of the combined approach in specific scenarios and the formalization of options for overcoming them.

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This study did not involve human participants, and therefore, informed consent was not required

Clinical Trial Registration

This research does not involve any clinical trials.

Author Contributions

Vyacheslav Lyashenko and Asaad Babker: Conceptualization, Methodology, Writing and Original Draft; Vyacheslav Lyashenko and Asaad Babker: Data Collection, Analysis, Writing Review and Editing; Vyacheslav Lyashenko: Visualization, Supervision, Project Administration; Asaad Babker, Rania Saad Suliman, Aisha Ali M Ghazwani ,Wiam AlHarbi: Funding Acquisition: Resources, Supervision; The final manuscript was read and approved by all authors.

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