https://doi.org/10.32603/1993-8985-2018-22-2-22-30
УДК 004.932.2

Natalya A. Obukhova, Alexander A. Motyko✉, Alexander A. Pozdeev
Saint Petersburg Electrotechnical University "LETI"
5, Professor Popov Str., 197376, St. Petersburg, Russia

RESEARCH AND DEVELOPMENT OF METHODS FOR ENDOSCOPIC (MEDICAL) IMAGES ENHANCEMENT

Abstract.
Introduction. *The modern technologies of virtual chromoendoscopy provide significant increase of diagnostic value of images considered by a doctor. The analysis of existing technologies shows that the existing solutions have significant disadvantages. Some of them require a complex preliminary calibration of the equipment for operation. Others use global transformations, making impossible consideration of local tissues characteristics and so on. In general, nowadays the technology of virtual chromoendoscopy, which suits the majority of potential users – doctors, does not exists, and, therefore, there it is a field for research.*
Objective. *Development of the method for virtual chromoendoscopy, with regard to disadvantages identified within the frames of carried out analysis of similar methods.*
Methods and materials. *For implementation of the research were used open endoscopic image data-bases, by the instrumentality of which, as a result of modeling and experiment, were evaluated quality characteristics of the proposed method.*
Results. *The new method of virtual chromoendoscopy. The main feature of the method is usage of nonlinear local transformation functions in transformation of RGB channels, as well as absence of calibration procedure for obtaining the effect of virtual chromoendoscopy. The proposed method is completely based on the technology of digital image processing and includes image brightness correction, which provides the possibility to obtain the necessary visual information both from very dark and overexposed fragments; image sharpening, contrasting small details and vessels.*
Conclusion. *The expert assessment of the obtained results shows that the visual effect of the proposed method corresponds, or in some cases, exceeds the visual effect of proprietary technologies of virtual endoscopy I-Scan and FICE.*

Key words: Virtual chromoendoscopy, digital medical image processing, nonlinear contrast enhancing

For citation: Obukhova N. A., Motyko A. A., Pozdeev A. A. Research and Development of Methods for Endoscopic (Medical) Images Enhancement. Journal of the Russian Universities. Radioelectronics. 2019, vol. 22, no. 2, pp. 22–30. doi: 10.32603/1993-8985-2018-22-2-22-30

Source of financing. This work was supported by the Russian Foundation for Basic Research, grant № 17-07-00045.

Conflict of interest. Authors declare no conflict of interest.

Received 27.02.2019; accepted 18.03.2019; published online 24.04.2019

Н. А. Обухова, А. А. Мотыко, А. А. Поздеев
Санкт-Петербургский государственный электротехнический университет "ЛЭТИ" им. В. И. Ульянова (Ленина)
ул. Профессора Попова, д. 5, Санкт-Петербург, 197376, Россия

ИССЛЕДОВАНИЕ И РАЗРАБОТКА МЕТОДОВ УЛУЧШЕНИЯ ЭНДОСКОПИЧЕСКИХ (МЕДИЦИНСКИХ) ИЗОБРАЖЕНИЙ

Аннотация.
Введение. *Современные технологии виртуальной хромоэндоскопии призваны существенно повысить диагностическую ценность предъявляемых врачу изображений. Анализ существующих технологий показывает, что имеющиеся решения не лишены значительных недостатков. Одни требуют для работы проведения сложной предварительной аппаратной калибровки, другие используют глобальные преобразования, не позволяющие учесть локальные особенности тканей, и т. д. В целом сейчас не существует технологии виртуальной хромоэндоскопии, устраивающей большинство потенциальных пользователей – врачей, а следовательно, есть поле для исследования.*
Цель работы. *Разработка метода для виртуальной хромоэндоскопии с учетом недостатков, выявленных у аналогов в результате анализа.*
Методы и материалы. *Для проведения исследований были использованы открытые базы данных эндоскопических изображений, с помощью которых в результате моделирования и эксперимента были оценены качественные характеристики предложенного метода.*
Результаты. *Новый метод виртуальной хромоэндоскопии, главная особенность которого – использование нелинейных локальных функций трансформации при преобразовании RGB-каналов, а также отсутствие процедуры калибровки для получения эффекта виртуальной хромоэндоскопии. Предложенный метод полностью основан на технологии цифровой обработки изображений, включает коррекцию яркости изображения, обеспечивающую возможность получения необходимой визуальной информации как из очень темных, так и из переэкспонированных фрагментов; повышение резкости изображения, подчеркивающее мелкие детали и сосуды.*
Заключение. *Экспертная оценка полученных результатов показывает, что визуальный эффект предложенного метода соответствует, а в отдельных случаях и превосходит визуальный эффект проприетарных технологий виртуальной эндоскопии I-Scan и FICE.*

Ключевые слова: виртуальная хромоэндоскопия, цифровая обработка медицинских изображений, нелинейное контрастирование

Для цитирования: Обухова Н. А., Мотыко А. А., Поздеев А. А. Исследование и разработка методов улучшения эндоскопических (медицинских) изображений // Изв. вузов России. Радиоэлектроника. 2019. Т. 22, № 2. С. 22–30. doi: 10.32603/1993-8985-2018-22-2-22-30

Источник финансирования. Работа выполнена при поддержке Российского фонда фундаментальных исследований, грант № 17-07-00045.

Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Статья поступила в редакцию 27.02.2019; статья принята к публикации 18.03.2019; опубликована онлайн 24.04.2019

Introduction. General information. Modern endoscopes play a significant role in diagnostics of gastrointestinal tract (GIT) diseases.

The demand to ensure high accuracy of differentiation of malignant tumors and manifestations of inflammatory processes during endoscopic examination stimulates development of new types of Image-Enhanced Endoscopy (IEE) systems on the basis of modern optical and digital technologies [1], [2]. IEE provides the higher specificity of the lesion morphology assessment by emphasizing the mucous membrane and capillaries microstructure.

The leading technology of the IEE direction is chromoendoscopy, which includes the dye-based chromoendoscopy and the electronic chromoendoscopy.

Chromoendoscopy based on the use of dying solutions is a technique that involves spraying of dyes harmless to human on the mucous surface of interest. Application of the dye enhances visualization of

the microstructure and vascular formations of the examined tissue.

Implementation of this technology requires only an aerosol catheter, which provides a relatively simple and economical method for the dye application. Despite these advantages, the use of solution-based chromoendoscopy for screening programs remains limited due to the lack of standardized research methods and techniques for the obtained images analysis. This limitation leads to the uncertainty in identification of the affected tissue.

The electronic chromoendoscopy implements the increase of medical images diagnostic value by emphasizing by color of the features of the analyzed tissues, mucous membranes or vessels based on optical and digital technologies. Nowadays, the electronic chromoendoscopy is implemented by the equipment for Narrow Band Imaging (NBI) [3] and Autofluorescence Images (AFI) [4].

NBI technology is developed by the company "Olympus". The equipment for illumination "Olympus" uses a backlight with a wavelength of 415 ± 15 nm and 540 ± 15 nm. The choice of wavelength is stipulated with the absorption spectrum of hemoglobin contained in the blood, due to which the vessels acquire a dark color against the background of pale surrounding tissue.

AFI technology is based on detection of natural tissue fluorescence stipulated by the presence of endogenous fluorophores in them. After excitation with the short-wave light source the fluorophores emit light with a longer wavelength, causing differences in the autofluorescence spectra of normal and affected tissues.

The application of optical filters required for the implementation of these technologies increases the complexity of the hardware and power consumption of the endoscopic system [5]. The alternative direction is post-processing of images obtained in white light, with the aim of modeling by the using optical filter digital methods – virtual chromoendoscopy.

The most well-known virtual chromoendoscopy technologies are: FICE (Fuji) [6], i-scan (PENTAX) [7], [8], SPICE SPECTRA (STOLZ) [9] and tri-scan [10].

The principle of FICE technology operation is based on the reconstruction of an image with a given wavelength from the RGB-coordinate values obtained by the sensor in white light. The synthesis of the reconstructed image is carried out using a linear transformation matrix of color spaces. FICE can create 300 types of spectral images with five different brightness and 60 different wavelengths in the range of visible light from 400 to 695 nm with a step of 5 nm. The basis of this technology is a complex calibration procedure using a spectrometer. The purpose of the calibration procedure is to identify the coefficients of color space transformation matrices.

The i-scan technology uses a three-step procedure of the image quality enhancement being formed: Surface Enhancement (SE), Contrast Enhancement (CE) and Tone Enhancement (TE). In SE mode, the brightness of the pixels at the edges of the objects is changed. CE enhances the blue component of the color in the dark fragments of the endoscopic image to emphasize the thin vessels and the heterogeneity of the mucous membrane. In TE mode, the RGB image obtained in white light is decomposed into separate R, G and B channels. Each channel is modified using a non-linear global transformation, followed by tonal curves, after which a three-component image is reconstructed.

Similar to i-scan, tri-scan technology includes three steps: Tissue and Surface Enhancement (TSE), Mucosa Layer Enhancement (MLE) and Color Tone Enhancement (CTE). TSE step uses a modified linear unsharp masking algorithm; in MLE step, the R-channel is converted using the sigmoid function. In CTE step, the intensity values of the pixels in each channel are distributed evenly to increase the color contrast.

The well-known company in the field of television endoscopic systems Karl Storz has developed the IMAGE1 S 4U hardware and software system, which includes elements of virtual chromoendoscopy [11]. The CLARA and CHROMA technologies included in the complex are used for leveling the illumination and enhancing the images contrast. In the SPIES SPECTRA B technology to increase the color contrast is used the color tone shift.

The implemented analysis of the existing technologies of virtual chromoendoscopy shows that:

– i-scan, tri-scan and SPIES SPECTRA B technologies use global transformations making impossible to consider the characteristics of each fragment of the image;

– FICE and SPIES SPECTRA A technologies require a complicated procedure of preliminary equipment calibration for selection of coefficients of the linear transformation matrix of color spaces.

Additionally, it is important to note that i-scan, FICE and SPIES SPECTRA technologies are proprietary technologies of major manufacturing companies of the endoscopic equipment, which makes difficult to conduct a comparative study of the effec-

tiveness and evaluation of the characteristics of the algorithms used.

The two-step method of virtual chromoendoscopy. Below is considered the method of virtual chromoendoscopy developed by the authors of the article, the features of which are the following:

1. The possibility to process each channel of the original image obtained in white light by separate procedures, the main feature of which is the use of adaptive (local) nonlinear contrasting technology, while all known solutions use global transformations. Global transformation means transformation, the type and parameters of which are constant for all image elements. In proposed local transformations, the parameters are set for each fragment of the image, depending on its features. Application of local algorithms for endoscopic images is more effective in contrast to global ones. This fact is determined by the important feature of endoscopic images – the simultaneous presence of significant dark and light areas stipulated by difficult conditions for obtaining of endoscopic images.

2. The absence of the calibration procedure to obtain the effect of virtual chromoendoscopy.

The proposed method is completely based on digital image processing technology.

In the image formed by the endoscopic camera, the R, G, B channels contain diverse in their spectrum responses from tissues located at different depths of the observed object. These responses depend on the spectral sensitivity curves of the sensor. Experiments have shown that the mentioned diversity of the sensitivity provides displaying different spatial elements [6]. Channel R contains exhaustive information about deep blood vessels and micro vessels, including ones located in deep layers of the mucous membrane. In channels G and B this information is almost completely absent. Thus, the features that are hardly noticeable in a white light image can be distinguished by improving the spatial characteristics separately in each channel. The proposed method implements the separate processing of each channel, which provides selection of fine structures and enables to study the characteristics of tissues, features of the mucosa and anomalous structures with greater efficiency in contrast to study of original image obtained in white light.

The developed method in the first step includes the contouring of vascular structures; in the second step – the tone correction, coloring of structural features in the areas of tissues to be examined by a doctor. Fig. 1 shows the structural scheme of the method.

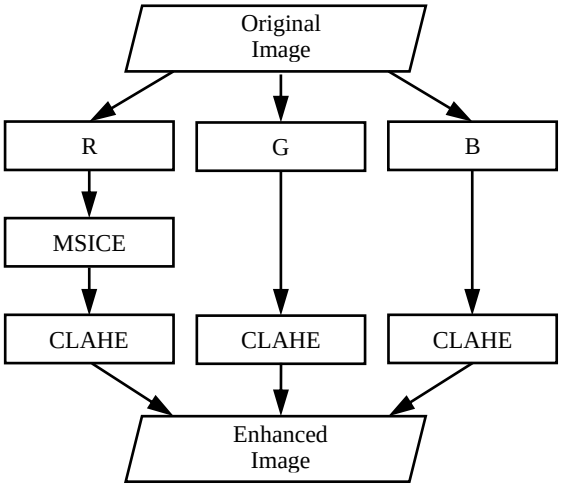


Fig. 1. Block diagram of a two-step method of virtual chromoendoscopy

Visualization of blood vessels. At the first step of the virtual chromoendoscopy method, the R channel is modified using the multi-scale image contrast enhancement procedure (MSICE) [12].

The algorithm implements the contrast enhancement based on the following nonlinear transformation functions:

$$G(x) = \frac{(B+A)x}{A+x}; \quad (1)$$

$$H(x) = \frac{Ax}{A+B-x}, \quad (2)$$

$$x = \overline{0,\ B},\ \ A,\ B \in \mathbb{R},$$

where x – input data; B – the maximum value of x (for images with a color representation of 8 bits per channel $B = 255$); A – coefficient, regulating the type of transformation function; $\mathbb{R}$ – a set of real numbers. Varying of A provides obtaining of different non-linear curves and controls the conversion between the input value of x and the out-put value of the transformation function $G(x)$ or $H(x)$. The function $G(x)$ increases the value of the input data in accordance with the coefficient A, while the function $H(x)$, on contrary, reduces the value of the input data.

The basic idea of the transformation is the following: for each pixel with the coordinates (i, j) of the original image, the difference between the value of its brightness Y_{ij} and the average brightness of its surroundings S_{ij} should be increased. If the condition $Y_{ij} > S_{ij}$, is true, in order to increase the pixel

brightness and thus the difference between its brightness and the average brightness of the cross-section area, is used the function $G(x)$. If $Y_{ij} > S_{ij}$, by function $H(x)$, the pixel brightness is reduced, also increasing the difference between its brightness and the average brightness of the cross-section area.

The average brightness value of the cross section of the pixel S_{ij_k} in the selected averaging zone with the diameter of *k* pixels is calculated as following:

$$S_{ij_k} = \frac{1}{(2k+1)^2} \sum_{y=i-k}^{i+k} \sum_{x=j-k}^{j+k} Y_{xy}. \quad (3)$$

The value of the coefficient *A* determines the degree of the initial pixel brightness Y_{ij} value change depending on the difference between Y_{ij} and S_{ij_k}. The small difference value should lead to a sharp change in the pixel brightness being processed to increase the local contrast. On the contrary, large values of the initial difference between the pixel brightness and the average brightness of a cross-section area cause slight changes, since the contrast in these cases is already sufficient.

A nonlinear change of the coefficient *A*, as well as a combination of equations (1), (2) and (3), lead to the following resultant transformation function for nonlinear contrasting:

$$\mathrm{Out}_{ij_k}(Y,\ S) = \begin{cases} \dfrac{\left[B + A\left(Y_{ij} - S_{ij_k}\right)\right]Y_{ij}}{A\left(Y_{ij} - S_{ij_k}\right) + Y_{ij}},\ Y_{ij} \geq S_{ij_k}; \\ \dfrac{A\left(S_{ij_K} - Y_{ij}\right)Y_{ij}}{A\left(S_{ij_K} - Y_{ij}\right) + B - Y_{ij}},\ Y_{ij} \geq S_{ij_k}; \end{cases}$$

$$A(x) = \begin{cases} M,\ x = 0; \\ M/x,\ x = \overline{1,\ B}, \end{cases}$$

where Out_{ij_k} is the corrected brightness value of a pixel with coordinates $(i,\ j)$ for the averaging zone of the diameter *k*; *M* is a constant that determines the degree of contrast. Small values of *M* lead to a expressed contrast, larger - to moderate one. Recommended by the authors value for fluorescent images obtained from the experiments performed is $M = 5000$.

The described procedure is implemented for the vicinity of three different cross-section areas; the final result is obtained by averaging:

$$\mathrm{Out}_{ij} = \frac{\mathrm{Out}_{ij_{k1}} + \mathrm{Out}_{ij_{k2}} + \mathrm{Out}_{ij_{k3}}}{3},$$

where Out_{ij} is the brightness value for a pixel with coordinates $(i,\ j)$. The vicinity cross-sections are determined by the properties of the processed images.

Three chosen spatial scales enable the influence on the lower, middle, and high image frequencies. Experimental studies have shown that for an image of 1024 × 768 size the reference point of pixels $k1 \approx 110$. The choice of this value as a reference point provides the opportunity to calculate the size of the averaging cross-section for other scales:

$$k_2 = k_1/2;\ \ k_3 = k_2/2.$$

Tone correction. The second step of the proposed method involves a separate procedure for brightness and contrast characteristics correcting for each channel. At this step, authors propose to use Contrast Limited Adaptive Histogram Equalization (CLAHE) [13], [14].

The CLAHE algorithm is a development of Histogram Equalization (HE) and Adaptive Histogram Equalization (AHE) equalization methods of the histogram. HE is a global method that implements the recalculation of the distribution of pixels brightness values for the entire image. The method increases the contrast over the entire image area, "stretching" from each other the most common brightness values in the histogram. Based on the method was proposed a local AHE method. AHE generates a histogram and redistributes the brightness values for the fragments into which the original image is pre-divided.

The CLAHE algorithm differs from the usual AHE one by the histogram constraint on a predetermined value found before calculating the distribution function. It has two key parameters: block size and histogram restriction level.

In the proposed virtual chromoendoscopy method, the following CLAHE implementation is used.

The original image is divided into non-overlapping blocks. Then each block is processed separately.

Step 1. A luminance histogram of the block is formed and a restriction level N_{CL} is determined:

$$N_{\mathrm{CL}} = N_{\mathrm{clip}} N_{\mathrm{avg}},$$

где N_{clip} – coefficient;

$$N_{\mathrm{avg}} = \left(N_{rx} N_{ry}\right) / N_{\mathrm{gray}}$$

where N_{rx}, N_{ry} – the number of pixels horizontally and vertically, respectively; N_{gray} – the number of brightness levels in the analyzed fragment.

If the number $N_{\text{reg}}(i)$ of block pixels in the brightness histogram, which have a brightness level *i*, is greater than N_{CL}, the excess pixels are removed from this level and redistributed to other levels of the histogram.

Step 2. Limitation of the luminance histogram. This step is represented by pseudo code, in which N_{cl_Σ} is the total number of pixels to be distributed; $H_{\text{reg\_cl}}(i)$ is the number of pixels with the *i*-th level of brightness in the limited brightness histogram:

$N_{\text{cl}_\Sigma} = 0;$
for $i = 0, \ldots, N_{\text{gray}} - 1$
  if $H_{\text{reg}}(i) > N_{\text{CL}}$ then
    $H_{\text{reg\_cl}}(i) = N_{\text{CL}};$
    $H_{\text{cl}_\Sigma} = H_{\text{cl}_\Sigma} + H_{\text{reg}}(i) - N_{\text{CL}};$
  end if
end for;
$H_{\text{avg\_gray}} = H_{\text{cl}_\Sigma} / N_{\text{gray}};$
for $i = 0, \ldots, N_{\text{gray}} - 1$
  if $H_{\text{reg}}(i) < \left(N_{\text{CL}} - H_{\text{avg\_gray}}\right)$ then
    $H_{\text{reg\_cl}}(i) = N_{\text{CL}} + H_{\text{avg\_gray}};$
    $H_{\text{cl}_\Sigma} = H_{\text{cl}_\Sigma} - H_{\text{avg\_gray}};$
  else if $H_{\text{reg}}(i) < N_{\text{CL}}$ then
    $H_{\text{reg\_cl}}(i) = N_{\text{CL}};$
    $H_{\text{cl}_\Sigma} = H_{\text{cl}_\Sigma} - N_{\text{CL}} + H_{\text{reg}}(i)$
  end if
end for;

Step 3. The remaining after the step 2 pixels of a number of H_{cl_Σ} are iteratively redistributed according to the brightness levels. The pseudo code corresponding to this procedure is:

while $N_{\text{cl}_\Sigma} > 0$
  for $i = 0, \ldots, N_{\text{gray}} - 1$
    if $H_{\text{reg\_cl}}(i) < N_{\text{CL}}$ then
      $H_{\text{reg\_cl}}(i) = H_{\text{reg\_cl}}(i) + 1;$
      $H_{\text{cl}_\Sigma} = H_{\text{cl}_\Sigma} - 1;$
    end if end for end while;

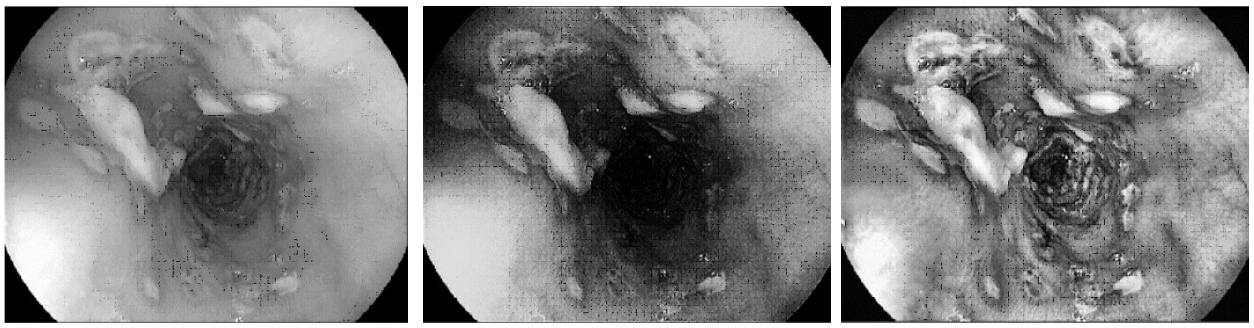
Step 4. Transformation of the cumulative distribution function of the limited brightness histogram of the block being processed according to the HE histogram equalization algorithm.

After processing all the blocks, bilinear interpolation is used to eliminate the boundary effect.

The results of the experiment. Experimental verification of the proposed method was carried out using our own database of colposcopic images (more than 100) and the open Kvasir endoscopic image database [15]. The Kvasir data set consists of 4000 images with different resolutions from 720 × 576 to 1920 × 1072 pixels.

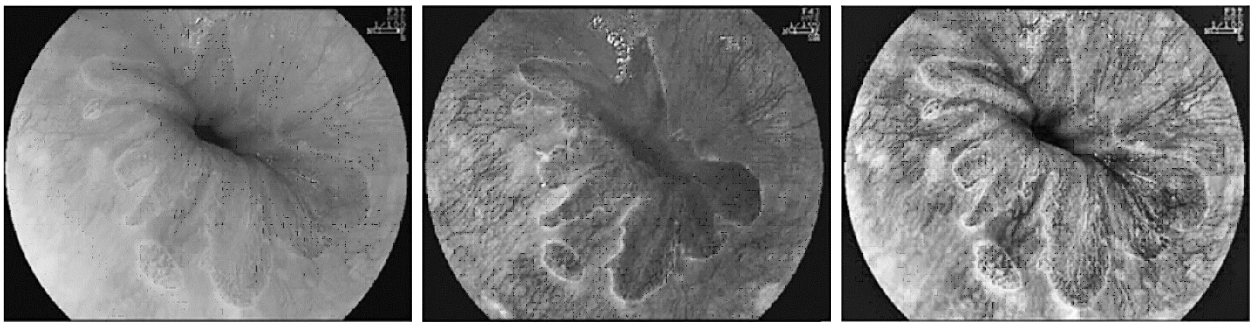
The images are divided into eight classes representing different cases of pathology. The expressed representativeness of the original images (several types of endoscopic examinations and pathologies, various types of sensors with the help of which images were obtained, as well as several resolution options) made it possible to carry out an in-depth study of the proposed method, to evaluate its effectiveness under different conditions. Examples of image processing using the proposed method are shown in comparison with the results of tri-scan, FICE and i-scan processing in Fig. 2–4 respectively.

To assess the image quality enhancement is used the Focus Value (FV) metric [16], representing the ratio of discrete-cosine transformations corresponding to the energy of the constant component and the energy of the other components of the image.



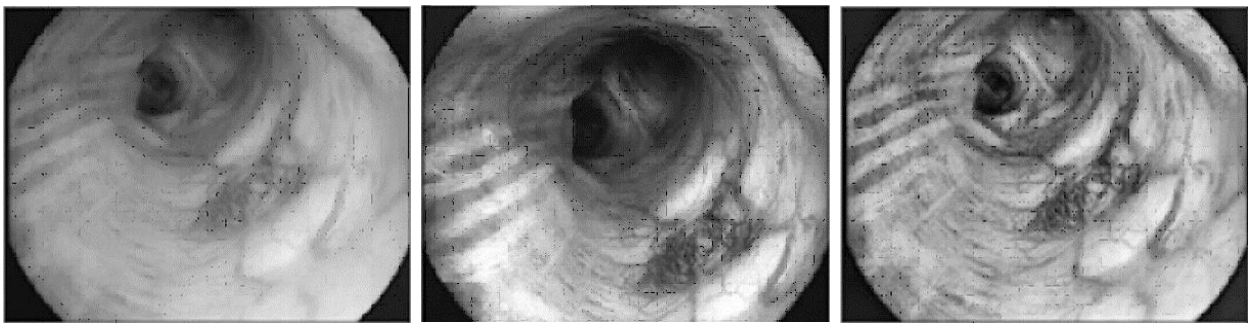
a *b* *c*

Fig. 2. Image processing by algorism tri-scan and proposed algorism:
a – the original image; *b* – the result of processing by tri-scan algorithm; *c* – the result of processing by the proposed algorithm



a *b* *c*

Fig. 3. Image processing by algorism FICE and proposed algorism:
a – the original image; *b* – the result of processing by FICE algorithm; *c* – the result of processing by the proposed algorithm



a *b* *c*

Fig. 4. Image processing by algorism i-scan and proposed algorism:
a – the original image; *b* – the result of processing by i-scan algorithm; *c* – the result of processing by the proposed algorithm

Conclusion. The table below shows the results of the FV metric calculation, averaged for various classes of endoscopic images. According to the obtained estimates it can be concluded that in all classes of images with different diagnoses from the Kvasir database, as well as on all images of the colposcopic image database, the FV metric obtained after the application of the described algorithm increases at least twice in comparison with the original image.

Experiments show that the proposed method implements:

– Correction of image brightness, providing the ability to obtain the required visual information from both very dark and overexposed fragments;

– Sharpening the image, emphasizing small details and vessels.

The expert evaluation of images obtained shows that the visual effect of the proposed method exceeds the result of tone correction using tri-scan, and also corresponds to or in some cases exceeds the visual effect of proprietary virtual endoscopy technologies i-scan and FICE.

Type of pathology	FV	
	Image	
	Original	Processed
Esophagitis	0.015	0.043
Dyed lifted polyps	0.031	0.069
Dyed resection margins	0.033	0.072
Normal seccum	0.025	0.067
Normal pylorus	0.014	0.043
Normal z-line	0.015	0.042
Polyps	0.025	0.059

REFERENCES

1. Won Young Cho, Jae Young Jang, Don Haeng Lee. Recent Advances in Image-enhanced Endoscopy. Clinical Endoscopy. 2011, vol. 44, no. 2, pp. 65–75. doi: 10.5946/ce.2011.44.2.65

2. Jae-Young Jang. The Past, Present, and Future of Image-Enhanced Endoscopy. Clinical Endoscopy. 2015, vol. 48, no. 6, pp. 466–475. doi: 10.5946/ce.2015.48.6.466

3. Machida H., Sano Y., Hamamoto Y., Muto M., Kozu T., Tajiri H., Yoshida S. Narrow-band Imaging in the Diag-

nosis of Colorectal Mucosal Lesions: a Pilot Study. Endoscopy, 2004, vol. 36, no. 12, pp. 1094–1098. doi: 10.1055/s-2004-826040.

4. Schmitz-Valckenberg S., Holz F. G., Bird A. C., Spaide R. F. Fundus Autofluorescence Imaging: Review and Perspectives. Retina. 2008, vol. 28, no 3, pp. 385–409. doi: 10.1097/IAE.0b013e318164a907.

5. Kaltenbach T., Sano Y., Friedland S., Soetikno R. American Gastroenterological Association (AGA) Institute Technology Assessment on Image-Enhanced Endoscopy. Gastroenterology. 2008, vol. 134, no. 1, pp. 327–340. doi: 10.1053/j.gastro.2007.10.062

6. FICE Atlas of Spectral Endoscopic images, 2008. Available at: https://en.fujifilmla.com/products/endoscopy/catalogs /pdf/index/fice-atlas-esp.pdf (accessed 09.03.2019)

7. PENTAX Medical i-scan Mini-Atlas for Gastroenterology, 2015. Available at: https://www.i-scanimaging.com /fileadmin/user_upload/PENTAX_i-scan_Mini-Atlas.pdf (accessed 09.03.2019)

8. Nishimura J., Nishikawa J., Nakamura M., Goto A., Hamabe K., Hashimoto Sh., Okamoto T., Suenaga M., Fujita Y., Hamamoto Y., Sakaida I. Efficacy of I-Scan Imaging for the Detection and Diagnosis of Early Gastric Carcinomas. Gastroenterology Research and Practice. 2014, no. 3, pp. 1–6. doi: 10.1155/2014/819395

9. Kamphuis G. M., de Bruin D. M., Fallert J., Gultekin M. H., de Reijke T. M., Laguna Pes M.P., de la Rosette J. J. M. C. H. Storz Professional Image Enhancement System: a New Technique to Improve Endoscopic Bladder Imaging. J. Cancer Sci Ther., 2016, vol. 8, no. 3, pp. 71–77. doi: 10.4172/1948-5956.1000394

10. Imtiaz M. S., Mohammed S. K., Deeba F., Wahid Kh. A. Tri-Scan: A Three Stage Color Enhancement Tool for Endoscopic Images. J. Medical Systems. 2017, vol. 41, no. 6, pp. 1–16. doi: 10.1007/s10916-017-0738-z

11. Karl Storz Endoscope. IMAGE1 S™ 4U – это не просто видеосистема. Available at: https://www.karlstorz.com /de/ru/telepresence.htm (accessed 09.03.2019)

12. Vonikakis V., Andreadis I. Multi-Scale Image Contrast Enhancement. Proc. 10th Int. Conf. on Control Automation Robotics and Vision. Hanoi, 17–20 December 2008. Piscataway: IEEE, 2008, pp. 856–861. doi: 10.1109 /ICARCV.2008.4795629

13. Pizer S. M., Amburn E. P., Austin J. D., Cromartie R., Geselowitz A., Greer Th. H., Romeny B. H., Zimmerman J. B., Zuiderveld K. Adaptive Histogram Equalization and Its Variations. Computer Vision, Graphics and Image Processing. 1987, vol. 39, no. 3, pp. 355–368. doi: 10.1016/S0734-189X (87)80186-X

14. Reza A. M. Realization of the Contrast Limited Adaptive Histogram Equalization (CLAHE) for Real-Time Image Enhancement. J. of VLSI Signal Processing. 2004, vol. 38, no 1, pp. 35–44. doi: 10.1023/B:VLSI.0000028532. 53893.82

15. The Kvasir Dataset. Available at: http://datasets. simula.no/kvasir (accessed 09.03.2019)

16. Shen C. H., Chen H. Robust Focus Measure for Low-Contrast Images. Int. Conf. on Consumer Electronics, ICCE'06. January, 7–11, 2006, Las Vegas. Digest of Technical Papers. Piscataway: IEEE, 2006, pp. 69–70. doi: 10.1109/ICCE.2006.1598314

Natalia A. Obukhova **–** Dr. of Sci. (Engineering) (2009), Professor (2004) of the Department of Television and Video Equipment of Saint-Petersburg Electrotechnical University "LETI". The author of more than 100 scientific publications. Area of expertise: digital image processing; applied television systems.
E-mail: natalia172419@yandex.ru

Alexander A. Motyko **–** Cand. of Sci. (Engineering) (2012), Associate Professor of the Department of Television and Video Equipment of Saint-Petersburg Electrotechnical University "LETI". The author of more than 50 scientific publications. Area of expertise: digital image processing; applied television systems.
http://orcid.org/0000-0003-4241-4298
E-mail: motyko.alexandr@yandex.ru

Alexander A. Pozdeev **–** Master on Radio Engineering (2016), Postgraduate Student, Assistant of the Department of Television and Video Equipment of Saint-Petersburg Electrotechnical University "LETI". The author of 10 scientific publications. Area of expertise: digital image processing; applied television systems.
E-mail: puches4@gmail.com

СПИСОК ЛИТЕРАТУРЫ

1. Won Young Cho, Jae Young Jang, Don Haeng Lee. Recent Advances in Image-enhanced Endoscopy // Clinical Endoscopy. 2011. Vol. 44, № 2. P. 65–75. doi: 10.5946/ce.2011.44.2.65

2. Jae-Young Jang. The Past, Present, and Future of Image-Enhanced Endoscopy // Clinical Endoscopy. 2015. Vol. 48, № 6. P. 466–475. doi: 10.5946/ce.2015.48.6.466

3. Narrow-band Imaging in the Diagnosis of Colorectal Mucosal Lesions: a Pilot Study / H. Machida, Y. Sano, Y. Hamamoto, M. Muto, T. Kozu, H. Tajiri, S. Yoshida // Endoscopy. 2004. Vol. 36, № 12. P. 1094–1098. doi: 10.1055/s-2004-826040.

4. Fundus Autofluorescence Imaging: Review and Perspectives / S. Schmitz-Valckenberg, F. G. Holz, A. C. Bird, R. F. Spaide // Retina. 2008. Vol. 28, № 3. P. 385–409. doi: 10.1097/IAE.0b013e318164a907.

5. American Gastroenterological Association (AGA) Institute Technology Assessment on Image-Enhanced Endoscopy / T. Kaltenbach, Y. Sano, S. Friedland, R. Soetikno // Gastroenterology. 2008. Vol. 134, № 1. P. 327–340. doi: 10.1053/j.gastro.2007.10.062

6. FICE Atlas of Spectral Endoscopic images, 2008. URL: https://en.fujifilmla.com/products/endoscopy/catalogs/pdf/index/fice-atlas-esp.pdf (дата обращения 09.03.2019)

7. PENTAX Medical i-scan Mini-Atlas for Gastroenterology, 2015. URL: https://www.i-scanimaging.com/fileadmin/user_upload/PENTAX_i-scan_Mini-Atlas.pdf (дата обращения 09.03.2019)

8. Efficacy of I-Scan Imaging for the Detection and Diagnosis of Early Gastric Carcinomas / J. Nishimura, J. Nishikawa, M. Nakamura, A. Goto, K. Hamabe, Sh. Hashimoto, T. Okamoto, M. Suenaga, Y. Fujita, Y. Hamamoto, I. Sakaida // Gastroenterology Research and Practice. 2014. № 3. P. 1–6. doi: 10.1155/2014/819395

9. Storz Professional Image Enhancement System: a New Technique to Improve Endoscopic Bladder Imaging / G. M. Kamphuis, D. M. de Bruin, J. Fallert, M. H. Gultekin, T. M. de Reijke, M.P. Laguna Pes, J. J. M. C. H de la Rosette // J. Cancer Sci Ther., 2016, Vol. 8, № 3. P. 71–77. doi: 10.4172/1948-5956.1000394

10. Tri-Scan: A Three Stage Color Enhancement Tool for Endoscopic Images / M. S. Imtiaz, S. K. Mohammed, F. Deeba, Kh. A. Wahid // J. Medical Systems. 2017. Vol. 41, № 6. P. 1–16. doi: 10.1007/s10916-017-0738-z

11. Karl Storz Endoscope. IMAGE1 S™ 4U – это не просто видеосистема. URL: https://www.karlstorz.com/de/ru/telepresence.htm (дата обращения 09.03.2019)

12. Vonikakis V., Andreadis I. Multi-Scale Image Contrast Enhancement // Proc. 10th Intern. Conf. on Control Automation Robotics and Vision. Hanoi, 17–20 Dec. 2008. Piscataway: IEEE, 2008. P. 856–861. doi: 10.1109/ICARCV.2008.4795629

13. Adaptive Histogram Equalization and Its Variations / S. M. Pizer, E. P. Amburn, J. D. Austin, R. Cromartie, A. Geselowitz, Th. H. Greer, B. H. Romeny, J. B. Zimmerman, K. Zuiderveld // Computer Vision, Graphics and Image Processing. 1987. Vol. 39, № 3. P. 355–368. doi: 10.1016/S0734-189X(87)80186-X

14. Reza A. M. Realization of the Contrast Limited Adaptive Histogram Equalization (CLAHE) for Real-Time Image Enhancement // J. of VLSI Signal Processing. 2004. Vol. 38, № 1. P. 35–44. doi: 10.1023/B:VLSI.0000028532.53893.82

15. The Kvasir Dataset. URL: http://datasets.simula.no/kvasir (дата обращения 09.03.2019)

16. Shen C. H., Chen H. Robust Focus Measure for Low-Contrast Images // Intern. Conf. on Consumer Electronics, ICCE'06, Jan. 7–11, 2006, Las Vegas. Digest of Technical Papers. Piscataway: IEEE, 2006, P. 69–70. doi: 10.1109/ICCE.2006.1598314

Обухова Наталия Александровна – доктор технических наук (2009), профессор (2004) кафедры телевидения и видеотехники Санкт-Петербургского государственного электротехнического университета "ЛЭТИ" им. В. И. Ульянова (Ленина). Автор более 100 научных работ. Сфера научных интересов – цифровая обработка изображений; прикладные телевизионные системы.
E-mail: natalia172419@yandex.ru

Мотыко Александр Александрович – кандидат технических наук (2012), ассистент кафедры телевидения и видеотехники Санкт-Петербургского государственного электротехнического университета "ЛЭТИ" им. В. И. Ульянова (Ленина). Автор более 50 научных работ. Сфера научных интересов – цифровая обработка изображений; прикладные телевизионные системы.
http://orcid.org/0000-0003-4241-4298
E-mail: motyko.alexandr@yandex.ru

Поздеев Александр Анатольевич – магистр по направлению "Радиотехника" (2016), аспирант, ассистент кафедры телевидения и видеотехники Санкт-Петербургского государственного электротехнического университета "ЛЭТИ" им. В. И. Ульянова (Ленина). Автор более 10 научных работ. Сфера научных интересов – цифровая обработка изображений; прикладные телевизионные системы.
E-mail: puches4@gmail.com