PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Determination of the time of occurrence of superficial damage to human biological tissues on the basis of colorimetry and fuzzy estimates of color types

Kvaterniuk, Serhii, Kvaterniuk, Olena, Petruk, Vasil, Rakytyanska, Hanna, Mokanyuk, Olexander, et al.

Serhii Kvaterniuk, Olena Kvaterniuk, Vasil Petruk, Hanna Rakytyanska, Olexander Mokanyuk, Zbigniew Omiotek, Aigul Syzdykpayeva, "Determination of the time of occurrence of superficial damage to human biological tissues on the basis of colorimetry and fuzzy estimates of color types," Proc. SPIE 11176, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2019, 111762B (6 November 2019); doi: 10.1117/12.2536411

SPIE.

Event: Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2019, 2019, Wilga, Poland

Determination of the time of occurrence of superficial damage to human biological tissues on the basis of colorimetry and fuzzy estimates of color types

Serhii Kvaterniuk*[a], Olena Kvaterniuk[b], Vasil Petruk[a], Hanna Rakytyanska[a], Olexander Mokanyuk[c], Zbigniew Omiotek[d], Aigul Syzdykpayeva[e]

[a]Vinnytsia National Technical University, Vinnytsia, Ukraine; [b]Vinnytsia Humanitarian Pedagogical College, Vinnytsia, Ukraine; [c]Vinnytsia National Medical University, Vinnytsia, Ukraine; [d]Lublin University of Technology, Lublin, Poland; [e]Sarsen Amanzholov East Kazakhstan State University, Ust-Kamenogorsk, Kazakhstan

ABSTRACT

Improved methods for surface imaging of the damaged human tissues based on colorimetry and fuzzy evaluation of color types are presented. Based on the color segmentation of images of superficial damage of human soft tissues, the original image is divided into zones of different colors in accordance with the reference colors used. Further, on the basis of calculated relative zones of different colors for a large set of experimental data on surface damage of biological tissues with a known time of occurrence of prescription, a fuzzy knowledge base is formed, what allows to classify damages and establish their time of occurrence. A bruise color is formalized by a fuzzy set defined on a discrete universal set of colors, where the degree of belonging of a fuzzy set corresponds to the degree of manifestation of each color in the coloring. The degree of coloration in a fuzzy set is determined on the basis of expert-experimental data on the percentage of the area of each color in the coloration. The relationship “time of occurrence of a bruise - coloring” is given in the form of fuzzy rules IF-THEN, which associate fuzzy estimates of time with fuzzy sets of color types. The time range is divided by the expert into intervals of the minimum duration, during which a change in the bruise color is recorded. The decision on the time of occurrence of a bruise is made on the basis of the degree of closeness of the observed and tabular fuzzy color sets.

Keywords: colorimetry, measurement, tissue characterization, fuzzy logic

1. INTRODUCTION

The condition of the surface pathologies of biological tissues significantly affects their color, so the analysis and classification of surface pathologies of biological tissues by color is particularly relevant for forensic diagnosis[1-3]. The coordinates of the color of the surface damage of human soft tissues are associated with the spectral characteristics of the diffuse reflectance, which depend on the structural and biophysical parameters of the affected tissues[4-9]. Solving the inverse optical problem, one can determine the biophysical characteristics of surface pathologies by color. For the definition and registration of colors used a scale of color samples that are compared with the color of the object of study. Data on the localization, shape, size and color of an object is recorded using a CCD camera, and color recognition and assessment of the state of an object using a computer diagnostic program. The Bureau of Forensic Medical Examination is provided with digital cameras and requires methods of analysis and classification of surface pathologies of biotissues. The proposed method is being tested on the basis of the Vinnitsa Regional Bureau of Forensic Medical Examination.

The relevance of the topic is due to the need to increase the reliability of determining the time of occurrence of superficial damage of human soft tissues with blunt objects in accordance with the tasks of forensic medicine, taking into account their optical-physical parameters by improving the method of colorimetry and developing appropriate hardware and software. The aim of the study is to increase the reliability of determining the time of occurrence of superficial damage to human soft tissues with blunt objects by color segmentation of images and the creation of appropriate hardware and software[14-16].

*serg.kvaternuk@gmail.com

Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2019,
edited by Ryszard S. Romaniuk, Maciej Linczuk, Proc. of SPIE Vol. 11176, 111762B
 · doi: 10.1117/12.2536411

At the first stage of the study, a bruise and a scale of color samples are photographed. The plane of the ruler and the main part of the bruise plane should be perpendicular to the axis of the camera. Side diffuse illumination using a diffuse reflector and a light source with a spectrum close to white. From the resulting raw image, fragments are cut out, corresponding to the bruise and colors on the ruler. Pixels in the image around the bruise are replaced with white in the CIELAB system. Further color correction is performed on the image and white balance. For each pixel of the bruise image, the Euclidean distance in the CIELAB space with the colors on the ruler is determined $L_{i,j}$. Image pixels with CIELAB coordinates corresponding to the white color are skipped, which allows you to discard pixels around a bruise. In the next image processing step, the color of the pixel is classified according to the color bar. For each pixel of the bruise image, the closest in line color is determined, to which the distance $L_{i,j}$ will be the shortest. For each bruise image, the number of pixels with a specific color is counted and their percentage is determined. The bruise area is defined as the ratio of the number of pixels of a bruise image to the number of pixels of a black square image with a known area on the color bar. As a result of image processing, a histogram of colors is obtained according to the chosen scale of color samples, which makes it possible to significantly simplify and formalize the procedure for analyzing the state of surface pathologies of biotissues in forensic diagnostics. Use for processing color images of surface damage of neural networks and neuro-fuzzy tissues can significantly improve the accuracy of diagnostic solutions[10-12].

2. USING COLOR IMAGE SEGMENTATION TO STUDY THE SUPERFICIAL DAMAGE OF HUMAN SOFT TISSUE

Based on the color image of the surface damage of human soft tissues with hard objects, you can get color coordinates for each pixel of the image in the CIELAB system. To establish the time of occurrence of superficial damage to human soft tissues with blunt objects, we determine the nearest colors from the scale of color samples for each picture element (Fig. 1).

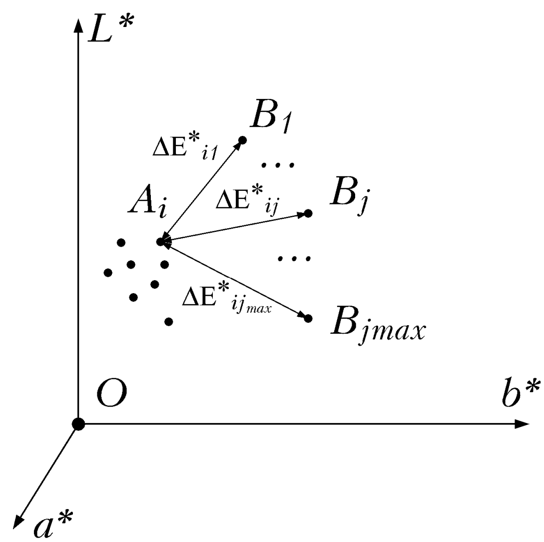


Figure 1. Determination of the full color difference in the CIELAB color space for an image element.

The full color difference $\Delta E^*_{ab\ ij}$ between the colors in the CIELAB color space is defined as follows:

$$\Delta E^*_{ab\ ij} = \sqrt{\left(\Delta L^*_{ij}\right)^2 + \left(\Delta a^*_{ij}\right)^2 + \left(\Delta b^*_{ij}\right)^2}\ , \tag{1}$$

$$\Delta L^*_{ij} = L^*_i - L^*_{scale\ j}\ ,\ \Delta a^*_{ij} = a^*_i - a^*_{scale\ j}\ ,\ \Delta b^*_{ij} = b^*_i - b^*_{scale\ j}\ , \tag{2}$$

where: L_i^*, a_i^*, b_i^* – coordinates in the color space of the image element; $L_{scale\,j}^*$, $a_{scale\,j}^*$, $b_{scale\,j}^*$ – coordinates in the color space of the color swatch element. The difference in lightness ΔL_{ij}^* practically does not give information on the state of the affected area of the biological tissue, therefore, when assessing the color difference, they should be neglected and determine the difference in color tone ΔH_{abij}^*. The difference in the purity of the tone in the system (L^*, a^*, b^*) between the element of the biotissue image and the element of the scale of color samples is determined by the formula:

$$\Delta C_{abij}^* = C_{abi}^* - C_{ab\,scale\,j}^*,\; C_{abi}^* = \sqrt{\left(a_i^*\right)^2 + \left(b_i^*\right)^2},\; C_{ab\,scale\,j}^* = \sqrt{\left(a_{j\,scale}^*\right)^2 + \left(b_{j\,scale}^*\right)^2}, \tag{3}$$

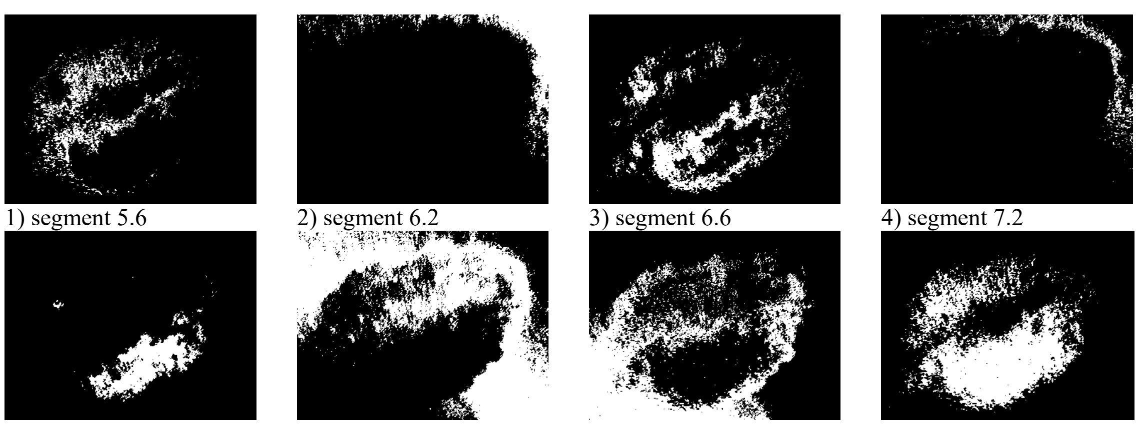
where: C_{abi}^* – the purity of the tone of the image element; $C_{ab\,scale\,j}^*$ – the purity of the tone element of the scale of color samples, a_i^*, b_i^* – color coordinates of the image element, $a_{scale\,j}^*$, $b_{scale\,j}^*$ – color coordinates of the color swatch element. The difference in color tone ΔH_{abij}^* between the element of the biotissue image and the element of the color sample scale is determined by the formula:

$$\Delta H_{abij}^* = k_H \sqrt{\left(\Delta E_{ab\,ij}^*\right)^2 - \left(\Delta L_{ij}^*\right)^2 - \left(\Delta C_{abij}^*\right)^2}, \tag{4}$$

where: $k_H = \begin{cases} +1,\ if\ \ a_i^* b_{ø\hat{e}j}^* - a_{ø\hat{e}j}^* b_i^* \geq 0; \\ -1,\ if\ \ a_i^* b_{ø\hat{e}j}^* - a_{ø\hat{e}j}^* b_i^* < 0. \end{cases}$

In the case of determining the nearest color from the scale of color samples for each image element k_H is taken equal to one. Thus, to determine the closest color from the color swatch scale for each image pixel, it is necessary to determine between which scale element B_j and the current image pixel the smallest color tone difference ΔH_{abij}^* in the CIELAB color space will be. It is necessary to assign the matrix element M_{ab} that corresponds to the current pixel of the image to the element number of the scale of color samples. By counting the number of matrix elements M_{ab} equal to the number of a certain color of the scale j, you can determine the area of a segment of a certain color in the image. For further processing and determination of biomedical damage parameters by color, it is necessary to convert the area of a certain color segment into a relative proportion of the total image area in percent and obtain a histogram of the colors of the surface damage image which indicates the relative sizes of different color zones[18-20].

An example of image processing of superficial skin damage in case of a mechanical lesion with a blunt object based on the algorithm for determining the nearest colors from the scale of color samples for each element is shown in Fig. 2.



1) segment 5.6 2) segment 6.2 3) segment 6.6 4) segment 7.2

5) segment 7.6 6) segment 8.2 7) segment 10.4 8) general image

Figure 2. An example of image processing of surface damage and segmentation into zones of different colors.

The feature of the obtained images, both individual zones of different colors of surface damage, and general images of surface damage is the presence of high-frequency noise in the images, as well as overlapping of damage zones of different colors with areas that match the color of intact skin[21-23,28,29].

3. THE EXPERT SYSTEM FOR DETERMINING THE TIME OF BRUISING BASED ON FUZZY ESTIMATES OF COLOR TYPES

The following principles are proposed for modeling the dependence “time of occurrence of a bruise – coloring”:

1. A bruise color is formalized by a fuzzy set defined on a discrete universal color set, where the degree of belonging of a fuzzy set corresponds to the degree of appearance of each color in the coloring.
2. The degree of coloration in the fuzzy set is determined on the basis of expert-experimental data on the percentage of the area of each color in the coloration[24].
3. The dependence “time of bruising - coloring” is given in the form of fuzzy rules, IF-THEN, which associate fuzzy estimates of time with fuzzy sets of color types. The time range is divided by the expert into intervals of the minimum duration during which a change in the bruise color is recorded[25].
4. The decision on the time of occurrence of a bruise is made on the basis of the degree of closeness of the observed and tabular (in the knowledge base) fuzzy color sets. Such a measure of proximity of fuzzy sets is Hamming distance[13]. The greater the Hamming distance, the smaller the similarity of the observed and table coloring[26,27].
5. Determining the time of occurrence of the bruise corresponds to the procedure of inverse logical inference on a fuzzy knowledge base by restoring the membership function of a fuzzy estimate of the time of occurrence. This membership function is restored according to the degrees of belonging of the observed fuzzy color set to the coloring type in the expert knowledge base.

In the method of processing images of bruises using fuzzy logic, we use the following notation: $\{c_1,...,c_n\}$ – set of bruise colors; $\{d_1,...,d_K\}$ – set of time counts to observe the dynamics of a change in bruise color; n – number of colors; K – number of test counts. Then the relationship "time (t) - the type of color (y)" can be described by a fuzzy knowledge base:

$$\text{IF } t \approx d_l \text{ THAT } y = T_l,\ l = \overline{1,K},$$

where: d_l – the value of the control timing, which corresponds to the type of color T_l; number of samples K matches the number of rules. The type of coloring is defined as a fuzzy set, which is given on a discrete universal color set $\{c_1,...,c_n\}$:

$$T_l = \left\{ \frac{\mu^{c_1}(T_l)}{c_1}, ..., \frac{\mu^{c_n}(T_l)}{c_n} \right\}, \tag{5}$$

where: μ^{c_i} – measure of color c_i intensity in bruise coloration. Time intervals d_l, $l = \overline{1,K}$, and set of bruise colors $\{c_1,...,c_n\}$ chosen by an expert. The experiment was conducted on the basis of the Vinnitsa Regional Bureau of Forensic Medicine. The knowledge base contains 20 rules. Time intervals cover 2 weeks (14 days, 335 hours) of observations. Let the observed bruise color type corresponds to a fuzzy set:

$$T^* = \left\{ \frac{\mu^{c_1}(T^*)}{c_1}, ..., \frac{\mu^{c_n}(T^*)}{c_n} \right\}. \tag{6}$$

The time of occurrence of a bruise will be described by a fuzzy set, which is given on a discrete universal set of time samples $\{d_1,...,d_K\}$:

$$D^* = \left\{ \frac{\mu^{d_1}(T^*)}{d_1}, ..., \frac{\mu^{d_K}(T^*)}{d_K} \right\}, \tag{7}$$

where: μ^{d_l} – the degree of belonging of the observed type of stain to the class d_l of the solution or the degree of confidence of the expert in the duration of the bruise $t = d_l$. Then the task of determining the time of occurrence of a bruise, which is the task of the inverse logical inference, is formulated as. For a given fuzzy set T^* on a fuzzy knowledge base, it is necessary to restore a fuzzy set D^*.

The algorithm for determining the time of occurrence of a bruise from fuzzy color estimates is to perform the following steps:

1. Fix a fuzzy set $y = T^*$ describing the original variable of the type of coloring.
2. Determine the Hamming distance between the observed and tabular types of color[13]:

$$\Delta_l(T_l, T^*) = abs(\mu^{c_1}(T_l) - \mu^{c_1}(T^*)) + ... + abs(\mu^{c_n}(T_l) - \mu^{c_n}(T^*)), \ l = \overline{1, K}. \quad (8)$$

Determine the degree of belonging or proximity $\mu^{T_l}(T^*)$ of the observed type of color T^* to the table types of color T_l:

$$\mu^{T_l}(T^*) = 1 - \Delta_l(T^*), \ l = \overline{1, K}. \quad (9)$$

3. Form a fuzzy set $t = D^*$ describing the input time variable. Since fuzzy sets are connected by the dependence “one input - one output”, then

$$D^* = \left\{ \frac{\mu^{T_1}(T^*)}{d_1}, ..., \frac{\mu^{T_K}(T^*)}{d_K} \right\}. \quad (10)$$

Step 3 corresponds to the restoration of the membership function of a fuzzy term $t = D^*$ that describes the time when the bruise occurred.

4. Consider the time of occurrence of a bruise class of decisions $t \approx d_j^*$, for which the degree of belonging, that is, the expert’s confidence measure, is maximum:

$$d_j^* = \max_{j=\overline{1,K}} (\mu^{d_j}(T^*)). \quad (11)$$

5. The set of solutions to the inverse problem, corresponding to the set of local maxima of the membership function of a fuzzy set D^*, is defined as the union of fuzzy sets $t \approx d_p$ [14-16]:

$$S^* = \underset{p}{\mathrm{U}} (d_p(T^*)), \ p = \overline{1, K^*}, \quad (12)$$

where: K^* – the number of time estimates for which the degree of significance (a measure of expert confidence) $\mu^{d_p}(T^*)$ is quite high.

The union operation in the set of solutions corresponds to the OR operation on fuzzy estimates of the time of the appearance of a bruise in the rules[17]. Let the “time of occurrence - type of stain” data on bruises 1–7 be obtained by expert experimental data (Tab. 1). Determine the time of occurrence of bruises 1-7 on a fuzzy knowledge base and compare with the reference time estimates. Hamming distances between the observed and tabular fuzzy sets are given in Table. 2.

Table 1. The initial data "time of occurrence of the bruise - the observed fuzzy sets".

Sample	Time of occurrence of bruise	Observed Fuzzy Sets T^*				
		5_2	6_2	7_2	8_2	10_4
bruise 1	0.5 – 1 hours	0.05	0.09	0.02	0.54	0.18
bruise 2	12 – 24 hours	0.17	0.12	0.01	0.37	0.16
bruise 3	48 – 72 hours	0.01	0.02	0.15	0.49	0.22
bruise 4	94 – 142 hours	0.10	0.21	0.30	0.25	0.18
bruise 5	142 – 190 hours	0.04	0.14	0.32	0.28	0.10
bruise 6	214 – 286 hours	0.03	0.15	0.21	0.43	0.08
bruise 7	286 – 358 hours	0.02	0.12	0.25	0.56	0.05

Table 2. Hamming distance between observed and tabular fuzzy sets.

No	Time of occurrence	Hamming distance between fuzzy sets T_l and T^*						
		bruise 1	bruise 2	bruise 3	bruise 4	bruise 5	bruise 6	bruise 7
1	30 seconds	0.42	0.43	0.41	0.84	0.78	0.64	0.8
2	5 minutes	0.16	0.51	0.27	0.9	0.84	0.6	0.5
3	15 minutes	0.22	0.19	0.39	0.56	0.58	0.36	0.5
4	30 minutes	0.25	0.54	0.5	0.95	0.73	0.47	0.37
5	1 hours	0.15	0.44	0.18	0.69	0.63	0.39	0.39
6	3 hours	0.09	0.4	0.34	0.81	0.75	0.51	0.41
7	6 hours	0.28	0.39	0.53	0.92	0.82	0.6	0.52
8	12 hours	0.25	0.18	0.4	0.59	0.65	0.43	0.61
9	24 hours	0.56	0.23	0.79	0.5	0.6	0.66	0.9
10	48 hours	0.23	0.58	0.18	0.79	0.73	0.49	0.39
11	70 hours	0.31	0.46	0.12	0.63	0.57	0.33	0.47
12	94 hours	0.54	0.35	0.51	0.36	0.3	0.28	0.42
13	118 hours	0.83	0.6	0.8	0.11	0.29	0.55	0.71
14	142 hours	0.74	0.63	0.71	0.18	0.12	0.38	0.54
15	167 hours	0.77	0.74	0.7	0.37	0.29	0.59	0.69
16	191 hours	0.65	0.6	0.54	0.47	0.21	0.27	0.33
17	214 hours	0.73	0.5	0.7	0.29	0.39	0.41	0.65
18	238 hours	0.54	0.51	0.51	0.46	0.3	0.1	0.26
19	262 hours	0.44	0.43	0.37	0.46	0.28	0.12	0.28
20	335 hours	0.56	0.85	0.55	0.74	0.52	0.4	0.16

Comparison of the initial and measured time of bruising is shown in Table 3. The initial and measured time of bruising coincide with a fairly high degree of confidence.

Table 3. Comparison of the initial and measured time of occurrence of bruise

Sample	Initial time of occurrence of bruise	The measured time of occurrence of bruise	
		Time interval	Measure of confidence
bruise 1	0.5 – 1 hours	1 – 12 hours	0.75 – 1
bruise 2	12 – 24 hours	12 – 36 hours 48 – 120 hours	0.62 – 0.80 0.41 – 0.62
bruise 3	48 – 72 hours	48 – 72 hours	0.80 – 0.90
bruise 4	94 – 142 hours	96 – 168 hours 192 – 240 hours	0.63 – 0.90 0.52 – 0.70
bruise 5	142 – 190 hours	120 – 168 hours 168 – 264 hours	0.70 – 0.89 0.61 – 0.80
bruise 6	214 – 286 hours	228 – 264 hours	0.87 – 0.91
bruise 7	286 – 358 hours	240 – 335 hours	0.73 – 0.84

4. CONCLUSIONS

An improved algorithm for determining the time of occurrence of a bruise using fuzzy color estimates made it possible to increase the accuracy of determining the time of appearance of superficial damage to human soft tissues with blunt objects based on image color segmentation and the corresponding hardware and software. An expert system was developed to determine the time of bruising on the basis of fuzzy estimates of coloration types and reverse inference, which allows the forensic expert to make the right decision. The expert system was introduced into the work of the Vinnitsa Regional Bureau of Forensic Medical Examination and tested on 1523 patients.

REFERENCES

[1] Petruk, V., Mokanyuk, O., Kvaternyuk, O., et al., "Changes of color coordinates of biological tissue with superficial skin damage due to mechanical trauma," Proc. SPIE 9816, (2015).

[2] Petruk, V., Kvaternyuk, O., Kvaternyuk, S., et al., "Methods and means of measuring control and diagnostics of biological tissues in vivo based on measurements of color coordinates and multispectral image," Proc. SPIE 9816, (2015).

[3] Petruk, V., Kvaternyuk, S., Kvaternyuk, O., et al., "Multispectral method and means for determining the distance of the shot on the basis of the study of gunshot injuries of the skin tissues," Przeglad elektrotechniczny 93(3), 129-132 (2017).

[4] Petruk, V. G., Kvaternyuk, S. M., Bolyuh, D. B., et al., "Research of the spectral diffuse reflectance of melanoma in vivo," Proc. SPIE 8698, (2012).

[5] Petruk, V. G., Ivanov, A. P., Kvaternyuk, S. M. and Barun, V. V., "Spectrophotometric Method for Differentiation of Human Skin Melanoma. II. Diagnostic Characteristics," Journal of Applied Spectroscopy 83(2), 261-270 (2016).

[6] Petruk, V. G., Ivanov, A. P., Kvaternyuk, S. M. and Barun, V. V., "Spectrophotometric Method for Differentiation of Human Skin Melanoma. I. Optical Diffuse Reflection Coefficient," Journal of Applied Spectroscopy 83(1), 85-92 (2016).

[7] Petruk, V., Kvaternyuk, O., Kvaternyuk, S., et al., "The optical diagnostics of parameters of biological tissues of human intact skin in near-infrared range," Proc. SPIE 10031, (2016).

[8] Omiotek, Z., Stepanchenko, O., Wójcik, W., Legieć, W. and Szatkowska, M., "The use of the Hellwig's method for feature selection in the detection of myeloma bone destruction based on radiographic images," Biocybern Biomed Eng 39(2), 328-338 (2019).

[9] Kvaternyuk, S., Petruk, V., Kvaternyuk, O., et al., "Multispectral measurement of parameters of particles in heterogeneous biological media," Proc. SPIE 10808, (2018).

[10] Petruk, V., Kvaternyuk, S., Kvaternyuk, O., et al., "Assessment of the validity of the diagnosis of damage of tissues by multispectral method using neural network," Przeglad elektrotechniczny 93(5), 106-109 (2017).

[11] Rotshtein, A., Shtovba, S., Chernovolik, G. and Petruk, V., "Processing of optical information for medical decision making support systems by intelligent techniques," Proc. SPIE 4425, (2001).

[12] Kvaternyuk, S., Kvaternyuk, O., Petruk, R., et al., "Indirect measurements of the parameters of inhomogeneous natural media by a multispectral method using fuzzy logic," Proc. SPIE 10808, (2018).

[13] Rotshtein, A. P., [Intellectual identification technologies: fuzzy sets, genetic algorithms, neural networks], UNIVERSUM, Vinnitsa, (1999).

[14] Rotshtein, A. and Rakytyanska, H., "Fuzzy Evidence in Identification, Forecasting and Diagnosis," Studies in Fuzziness and Soft Computing 275, 313 (2012).

[15] Rakityanskaya, A. B. and Rotshtein, A. P., "Fuzzy relation-based diagnosis," Automation and Remote Control 68(12), 2198-2213 (2007).

[16] Rotshtein, A. and Rakytyanska, H., "Adaptive diagnostic system based on fuzzy relations," Cybern. Syst. Anal. 45(4), 623-637 (2009).

[17] Rakytyanska, H., "Fuzzy classification knowledge base construction based on trend rules and inverse inference," Eastern-European Journal of Enterprise Technologies 1(3), 25-32 (2015).

[18] Zabolotna, N. I., Pavlov, S. V., Radchenko, K. O., et al., "Diagnostic efficiency of Mueller - matrix polarization reconstruction system of the phase structure of liver tisssue," Proc. SPIE 9816, (2015).

[19] Kozlovska, T. I., Kolisnik, P. F., Zlepko, S. M., et al., "Physical-mathematical model of optical radiation interaction with biological tissues," Proc. SPIE 10445, (2017).

[20] Vyatkin, S. I., Romanyuk, A. N., Gotra, Z. Y., et al., "Offsetting, relations and blending with perturbation functions," Proc. SPIE 10445, (2017).

[21] Omiotek, Z., "Improvement of the classification quality in detection of Hashimoto's disease with a combined classifier approach," P I Mech Eng H 231(8), 774-782 (2017).

[22] Wojcik, W., Lach, Z., Smolarz, A., et al., "Power supply via optical fibre in home telematic networks," Przeglad elektrotechniczny 84(3), 277-279 (2008).

[23] Pavlov, S. V., Kozhukhar, A. T., et al., "Electro-optical system for the automated selection of dental implants according to their colour matching," Przeglad elektrotechniczny 93(3), 121-124 (2017).

[24] Kholin, V. V., Chepurna, O. M. Pavlov, S., et al., "Methods and fiber optics spectrometry system for control of photosensitizer in tissue during photodynamic therapy," Proc. SPIE 10031, (2016).

[25] Rovira, R. H., Tuzhanskyy, S. Ye., Pavlov, S. V., Savenkov, S. N., Kolomiets, I. S., et al., "Polarimetric characterisation of histological section of skin with pathological changes," Proc. SPIE 10031, (2016).

[26] Lizak, T., Szypulski, M., Zarzeczny, D., Muzyka, K. and Kociubiński, A., "Modeling and simulation of nichrome microheater on polycarbonate substrate," Proc. SPIE 10808, (2018).

[27] Rovira, R., Bayas, M. M., Pavlov, S. V., Kozlovskaya, T. I., Kisała, P., et al., "Application of a modified evolutionary algorithm for the optimization of data acquisition to improve the accuracy of a video-polarimetric system," Proc. SPIE 9816, (2015).

[28] Ławicki, T., "Odszumianie obrazów CT za pomocą transformaty curvelet," Przeglad Elektrotechniczny 2(91), 222-224 (2015).

[29] Prokop, P., "Zastosowanie metody Chan-Vese w segmentacji obrazów medycznych," Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Srodowiska 4, 32-37 (2015).