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Processing multispectral images of the surface of biotissues using fuzzy logic

***Abstract**. The method uses multispectral image segmentation based on measuring diffuse reflection coefficients at certain wavelengths of spectral channels, solving the inverse optical problem of determining the concentrations of hemoglobin destruction products in the near-surface biotissues, filtering and segmentation of the image, calculating the relative sizes of segments and determination of damages using fuzzy logic.*

Streszczenie.** Metoda wykorzystuje wielospektralną segmentację obrazu opartą na pomiarze współczynników odbicia rozproszonego przy określonych długościach fali kanałów widmowych, rozwiązując odwrotny problem optyczny określania stężeń produktów niszczenia hemoglobiny w biotekstach powierzchniowych, filtrowania i segmentacji obrazu, obliczania względnych rozmiarów segmentów i określanie uszkodzeń za pomocą logiki rozmytej.(**Przetwarzanie obrazów wielospektralnych powierzchni biotkank za pomocą logiki rozmytej)

Keywords: multispectral image, biological tissue, forensic examination, fuzzy logic.
Słowa kluczowe: obraz wielospektralny, tkanka biologiczna, badanie kryminalistyczne, logika rozmyta.

Introduction

In the study of superficial injuries of human soft tissues as a result of trauma with a blunt object in forensic medicine, it is necessary to document the extent of the damage, analyze its features and determine the time elapsed since the damage was done. The relevance of the topic is due to the need to increase the reliability of diagnosing the state of superficial injuries of human soft tissues in accordance with the tasks of forensic medicine.

Measuring the optical parameters of superficial soft tissue injuries allows obtaining objective information about the content of certain pigments in them and about their structure, which can be used for diagnostics in the tasks of forensic medicine.

Determination of the parameters of the surface layer of inhomogeneous biological media of different origin is based on a direct problem - mathematical modeling of the spectral characteristics of this layer with its known parameters (pigment concentration, characteristics of structural elements) and the inverse problem - determination of the required parameters of the surface layer with the spectral characteristics or neuro-fuzzy network [1-3]. In this case, the use of multispectral images is processed in each pixel of the image.

Having solved the inverse optical problem, it is possible to determine the content of hemoglobin destruction pigments in the surface damaged and to segment its surface into sections depending on their content. To assess the morphological and functional changes in surface damage, an empirical model has been developed for the dependence of the relative sizes of surface damage segments with specific concentrations of hemoglobin destruction products when the age of injury has changed [4]. This allows you to set the duration of injury on the basis of processing the size of segments of multispectral images of superficial damage to human skin.

Compared with previous works on determining the time of occurrence of damage to human soft tissues as a result of trauma with blunt objects based on processing color coordinates and segmenting color images [5, 6], the use of multispectral images should increase the reliability of diagnostics due to the greater information content of multispectral images obtained in the necessary narrow spectral bands. If we take into account differences in the concentrations of hemoglobin destruction products within one surface damage, then its image can be divided into several segments with different multispectral parameters. Separation of a multispectral image into segments is carried out using fuzzy logic through training using histological and biochemical analysis data.

Consider a mathematical model of the effect of morpho-functional changes in surface damage on its optical characteristics. Interpretation of changes in the optical parameters of surface damage to human biological tissues, which are the result of their morpho-functional changes, requires the development of a physical model of biological tissue in which the geometric dimensions of the structural elements and the spatial distributions of its main pigments must be entered.

Such a model can be created on the basis of a comparison of the results of a theoretical description of the processes of propagation of optical radiation in biological tissues and experimental in vivo studies of their optical parameters. Such a model can be created on the basis of a comparison of the results of a theoretical description of the processes of propagation of optical radiation in biological tissues and experimental in vivo studies of their optical parameters.

The mechanical effect of solid blunt objects on biological tissue is accompanied by damage and rupture of subcutaneous and deep vessels with bleeding from them. Blood accumulated in the lesion site shines through the skin, forming a bruise. The concept of “bruise” unites accumulations of blood of varying origins and intensities in the thickness of the soft tissues and in the intervals between them.

Bruising under mechanical lesions arise due to bleeding mainly of small arteries and arterioles [7]. Immediately after injury, as a result of mechanical damage to human skin with a blunt object, microvessels and capillaries in the dermis layers are damaged, and a large amount of blood is poured into the surface layers of the skin. To create a mathematical model of the affected biological tissue, we assume that the volume content of blood in the dermis will increase to 20-50% compared to 1-6% for normal intact skin. We calculate the spectral characteristics of the diffuse reflection coefficient from individual layers of the pathological skin biological tissue with different volumetric blood content in Mathcad 13.0, the simulation results are shown in Fig. 1.

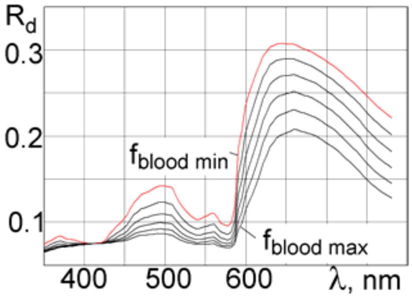

Fig.1. Spectral characteristics of the fraction of the diffuse reflectance from individual layers of the pathological skin tissue with different volume content of blood

After damage to biological tissue, surface damage occurs in which biochemical and structural changes occur over a long time [8]. The blood that has penetrated the surface layer gradually changes its properties. There is a process of deoxygenation of hemoglobins in injured tissues, their transition to methemoglobin, and this, in turn, to bilirubin.

These processes lead to a change in light scattering and transformation of optical radiation in damaged areas of the skin and, as a result, changes in their color [9-11], as well as electrical conductivity and thermal conductivity. In the first hours (2-4 hours), blood that has penetrated from the vessels contains oxyhemoglobin, which provides a bright red color to the bruise. Further, due to the absorption of oxygen by surrounding tissues, oxyhemoglobin passes into reduced hemoglobin with a dark red color of the bruise with a bluish tint.

After 1 day, the recovered hemoglobin goes into methemoglobin with the addition of a violet hue. At this stage of the bloom, the bruise decreases, as methemoglobin is more resistant than oxyhemoglobin. Then methemoglobin gradually turns into biliverdin and verdohemochromogen, having a green color. This gives the blood bloom first a blue-purple color, and then a brownish-yellow color. After that, the color changes to green, and green to yellow with the formation of bilirubin on the fifth to sixth day, which gives yellow color, gradually weakens and disappears. Since the bruise is a manifestation of mechanical damage to soft tissues, aseptic inflammation occurs in it, the maximum of which occurs after 2 days and completely disappears by 16-18 days.

The splitting of the hemoglobin molecule may also occur differently: in the reticuloendothelial system, hemoglobin is first transformed into an unstable protein, the hemochromogen, which is rapidly oxidized to verdohemocromogen (green pigment). The latter, splitting, loses iron, together with proteins forms biliverdin and globin. Biliverdin is easily restored, turning into bilirubin. The change in the color of the bruise also depends on the predominance of one type of hemoglobin transformation. The generally accepted scheme of establishing limitation on the "bloom" of the bruise is as follows [6]: in the first 2 hours, the bruise manifests itself in the form of red-purple swelling due to the presence of oxyhemoglobin in the hemorrhage.

Over the next 6-12 hours, it acquires a blue-purple hue as a result of the transition of oxyhemoglobin to restored hemoglobin. By the end of the first day after the lesion, the recovered hemoglobin passes into methemoglobin, giving a bruise a blue-violet hue. By the end of the second day - the beginning of the third day - a green shade is added around the edges due to the formation of biliverdin and verdohemocromogen, the intensity of which increases and persists up to 5-8 days, sometimes up to 10 days.

On the 7th day, a yellowish (yellowish-brown) hue appears on the periphery of the hemopathy due to the formation of bilirubin and hemosiderin. By this time, the bruise in the central part retains a bluish color in the middle part and a green color in the middle zone. This condition can persist up to 10 days post-traumatic period. At 10-15 days at the stage of yellowish color, the bruise gradually disappears. These periods are averaged and their fluctuations depend on many factors (volume of blood in the affected area, localization of the bruise, general condition of the body, type of treatment and the presence of associated diseases) [12, 13]. Experimentally obtained concentrations of hemoglobin derivatives in bruise biological tissues at different time intervals after injury have been calculated in Mathcad 13.0, the diffuse reflectance of the skin (Fig. 2).

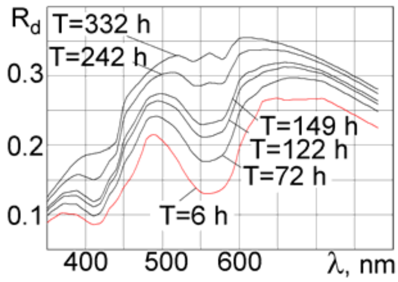

Fig.2. Spectral characteristics of the diffuse reflectance of damaged skin with a bruise when the age of damage changes

The aim of the work is to increase the reliability of establishing the time elapsed after the occurrence of superficial injuries of human soft tissues by processing multispectral images of these injuries and using fuzzy logic.

Methods

The method uses multispectral image segmentation based on measuring diffuse reflection coefficients at certain wavelengths of spectral channels, solving the inverse optical problem of determining the concentration of hemoglobin destruction products in near-surface biotissues, filtering and segmentation of the image into areas with a specific concentration of hemoglobin decomposition products, calculating the relative sizes of the parts and determining damages using fuzzy logic.

The coordinates in the multispectral space M_j are determined on the basis of the spectral characteristics of the radiation sources $P_j(\lambda_i)$, the sensitivity of the camera in each spectral channel $m_j(\lambda_i)$, and the spectral characteristics of the diffuse reflectance of the test object $\rho(\lambda_i)$:

$$\begin{cases} M_1 = \sum_{i=1}^{i_{\max}} P_1(\lambda_i)\overline{m_1}(\lambda_i)R_d(\lambda_i)\Delta\lambda, \\ M_2 = \sum_{i=1}^{i_{\max}} P_2(\lambda_i)\overline{m_2}(\lambda_i)R_d(\lambda_i)\Delta\lambda \\ \ldots \\ M_n = \sum_{i=1}^{i_{\max}} P_n(\lambda_i)\overline{m_n}(\lambda_i)R_d(\lambda_i)\Delta\lambda. \end{cases} \quad (1)$$

Based on multispectral images of surface damage of human soft tissues with hard objects, one can obtain coordinates in the multispectral space for each pixel of the image. In accordance with the rule to establish the limitation of the occurrence of superficial damage to human soft tissues with blunt objects [14], we determine the nearest coordinates from the sample scale for each image element (Fig. 3).

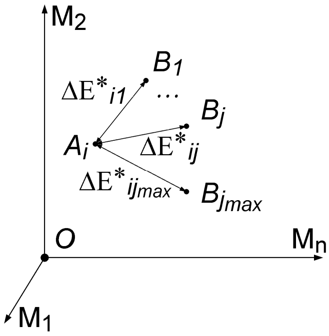

Fig.3. Definition in the multispectral space of the nearest elements from the sample scale

The distance $\Delta E^*_{ab\,ij}$ between the coordinates for a particular pixel and the scale elements in the multispectral space is determined as follows:

(2) $$\Delta E_{ab\,ij} = \sqrt{\left(\Delta M1_{ij}\right)^2 + \left(\Delta M2_{ij}\right)^2 + ... + \left(\Delta Mn_{ij}\right)^2},$$

where $\Delta Mn_{ij} = Mn_i - Mn_{scale\,j}$, Mn_i – the coordinates in the multispectral space of the image element; $Mn_{scale\,j}$ – the coordinates in the multispectral space of the element of the sample scale.

An example of image processing of superficial skin damage in case of a mechanical lesion with a blunt object based on the definition of the closest elements of the sample scale for each image element is shown in Fig. 4.

Thus, to determine the closest element from the sample scale for each image pixel, it is necessary to determine between which the scale element B_j and the current image pixel will be the smallest difference in the multispectral space $\Delta E_{ab\,ij}$. 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 sample scale. By counting the number of elements of the matrix M_{ab} equal to the number of a specific element of the scale j, we can determine the area of a segment in the image.

For further processing and determination of biomedical damage parameters, it is necessary to convert the area of the segment to the relative share of the total image area in percent and obtain a histogram of the segments of surface damage in which the relative sizes of the segments are indicated. The calculation by the formula (2) is carried out $i \times j$ times, where i is the number of elements (pixels) of the image, j is the number of elements of the scale.

Results

The dependence of the relative sizes of segments of multispectral images on the prescription of the appearance of superficial damage of human soft tissues using their processing with the help of fuzzy logic was experimentally revealed.

A typical relationship between the relative areas of the multispectral image segments can be defined as an interval fuzzy set:

(3) $$Z_p = \left\{ \frac{[\underline{\mu}^{c_{1p}}, \overline{\mu}^{c_{1p}}(t)]}{c_1}, ..., \frac{[\underline{\mu}^{c_{np}}, \overline{\mu}^{c_{np}}]}{c_n} \right\}, \quad p = \overline{1, N},$$

which is defined on a discrete universal set, the ratio of the area of segments $\{c_1,...,c_n\}$, where n is the number of all image segments, N – is the number of base segments that are used to establish limitation, $\underline{\mu}^{c_{ip}}$, $\overline{\mu}^{c_{ip}}$ – is the lower and upper limits of the degree of intensity or degree of color c_i development in the basic type of color Z_p.

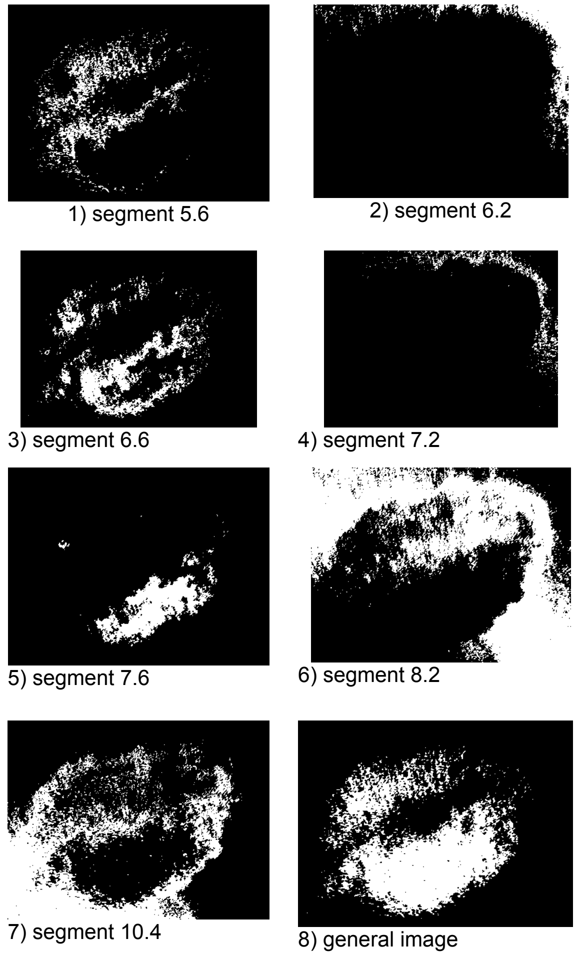

Fig. 4. Surface damage segmentation example

Then the dependence "time (t) – the type of color (y)" can be described by a fuzzy knowledge base:

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

where T_l – the type of color at the time d_l; the number of samples K corresponds to the number of rules.

If we interpret the obtained values as the weights of the rules, then the interval fuzzy sets of color types T_l in (4) can be obtained as follows:

(5) $$T_l = \left\{ \frac{\left[\max\limits_{p=1,N}(w_{pl} \cdot \underline{\mu}^{c_{1p}}), \max\limits_{p=1,N}(w_{pl} \cdot \overline{\mu}^{c_{1p}})\right]}{c_1}, ..., \frac{\left[\max\limits_{p=1,N}(w_{pl} \cdot \underline{\mu}^{c_{np}}), \max\limits_{p=1,N}(w_{pl} \cdot \overline{\mu}^{c_{np}})\right]}{c_n} \right\}$$

where $l = \overline{1, K}$ w_{pl} – is the weight of the basic type of coloring Z_p in the rule with the number l.

Time intervals d_l, $l = \overline{1,K}$ were elected by the forensic expert of the Vinnitsa Regional Bureau of Forensic Medicine. The knowledge base contains 18 rules. The time intervals in (3) cover 2 weeks (14 days, 335 hours) of observations. We solve the problem of restoring the age of the bruise by type of stain. Let the observed bruise color type corresponds to a fuzzy set

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

The duration of the bruise will be described by a fuzzy set

(7) $$D^* = \left\{ \frac{[\underline{\mu}^{d_1}, \overline{\mu}^{d_1}]}{d_1}, ..., \frac{[\underline{\mu}^{d_K}, \overline{\mu}^{d_K}]}{d_K} \right\},$$

Here $\underline{\mu}^{d_l}, \overline{\mu}^{d_l}$ – are the lower and upper bounds of the degree of belonging of the observed type of stain to the class of the decision d_l or the degree of confidence of the expert in the limitation of the bruise $t=d_l$.

Then the task of restoring the age of the bruise, which is the problem of the reverse logical inference, is formulated as. For a given fuzzy set T^* on a fuzzy knowledge base (4), it is necessary to restore a fuzzy set D^*.

Algorithm for restoring the age of the bruise by fuzzy estimates of the type of staining.

– fix fuzzy set $y = T^*$ (6), which describes the original variable of the type of color.

– determine the Heming distance between the fuzzy set of the observed type of color (6) and the fuzzy sets (5) from the knowledge base. For class boundaries T_l, $l = \overline{1,K}$ the Hamming distance will be in the interval:

$$\Delta_l(T_l, T^*) = [\min(\Delta_l^1, \Delta_l^2), \max(\Delta_l^1, \Delta_l^2)],$$

where

$$\Delta_l^1(T_l, T^*) = abs(\underline{\mu}^{c_1}(T_l) - \mu^{c_1}(T^*)) + ... + abs(\underline{\mu}^{c_n}(T_l) - \mu^{c_n}(T^*)),$$

$$\Delta_l^2(T_l, T^*) = abs(\overline{\mu}^{c_1}(T_l) - \mu^{c_1}(T^*)) + ... + abs(\overline{\mu}^{c_n}(T_l) - \mu^{c_n}(T^*))$$

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

$$\underline{\mu}^{T_l}(T^*) = 1 - \max(\Delta_l^1, \Delta_l^2),$$

$$\overline{\mu}^{T_l}(T^*) = 1 - \min(\Delta_l^1, \Delta_l^2).$$

If the Hamming distance is greater than 1, then the degree of membership is 0.

– to form the interval fuzzy set $t = D^*$ (7), which describes the input time variable. Since fuzzy sets (6) and (7) connect the dependence "one input - one output", then

$$D^* = \left\{ \frac{[\underline{\mu}^{T_1}, \overline{\mu}^{T_1}]}{d_1}, ..., \frac{[\underline{\mu}^{T_K}, \overline{\mu}^{T_K}]}{d_K} \right\}.$$

The step corresponds to the restoration of the interval function of belonging of a fuzzy term $t = D^*$ describing the duration of the bruise.

– consider the class of decisions $t \approx d_j^*$ for which the degree of belonging, that is, the expert's confidence measure, is the maximum:

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

– the set of solutions of 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 $t \approx d_J$ [14]:

(8) $$S^* = \bigcup_J (d_J(T^*)),\ J = \overline{1,K^*},$$

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

The operation of combining in the plural number of solutions (8) corresponds to the operation OR on fuzzy estimates of the age of the bruise in rules [15, 16]. Let expertly and experimentally obtain data "prescription-type coloring" about bruises 1-7 (Table 1).

Table 1 – Background data „old bruise - observable fuzzy sets"

№	Reference age of the bruise	Observed fuzzy sets T^*				
		5_2	6_2	7_2	8_2	10_4
1	0.5 – 1 hours	0.03	0.21	0.10	0.64	0.18
2	12 – 24 hours	0.21	0.20	0.28	0.67	0.26
3	48 – 72 hours	0.09	0.12	0.30	0.45	0.16
4	96 – 144 hours	0.07	0.10	0.35	0.38	0.10
5	168 – 190 hours	0.10	0.35	0.50	0.63	0.10
6	192 – 240 hours	0.04	0.30	0.30	0.68	0.09
7	240 – 288 hours	0.05	0.35	0.38	0.76	0.10

Let's restore the prescription of bruises 1-7 on a fuzzy knowledge base and compare with the reference time estimates. As the observed fuzzy color set approaches the class boundaries, the values of the limits of the interval fuzzy set for the age of the bruise increase. As the bruise increases, the degree of uncertainty, that is, the difference between the lower and upper boundaries of the restored membership function, increases.

Let's restore the prescription of bruises 1-7 on a fuzzy knowledge base and compare with the reference time estimates. As the observed fuzzy color set approaches the class boundaries, the values of the limits of the interval fuzzy set for the age of the bruise increase. As the bruise increases, the degree of uncertainty, that is, the difference between the lower and upper boundaries of the restored membership function, increases.

Comparison of reference and restored bruises are shown in Tabl. 2. For comparison, the average estimates were used. Comparison of reference and restored bruises are shown in to construct the membership functions of the basic types of color and the reconstructed time estimates.

Table 2. Comparison of reference and restored bruising

№	Reference age of the bruise, h	Model age of the bruise					
		Exact affiliation functions			Interval method		
		Age of damage h	Measure of significance	Accuracy, h.	Age of damage h.	Measure of significance	Accuracy, h
1	[0.5, 1]	[1, 12]	[0.75, 1]	$\pm$ 12	[0, 3]	[0.59, 0.78]	$\pm$ 2
2	[12, 24]	[12, 36]	[0.62, 0.80]	$\pm$ 12	[8, 24]	[0.81, 0.90]	$\pm$ 4
3	[48, 72]	[48, 72]	[0.80, 0.90]	0	[48, 72]	[0.78, 0.83]	0
4	[96, 144]	[96, 168]	[0.63, 0.90]	$\pm$ 24	[120, 144]	0.82	$\pm$ 24
5	[144, 190]	[120, 168] [168, 264]	[0.70, 0.89] [0.61, 0.80]	$\pm$ 24 $\pm$ 72	[168, 192]	0.93	$\pm$ 24
6	[216, 240]	[228, 264]	[0.87, 0.91]	$\pm$ 48	[216, 240]	0.86	0
7	[240, 288]	[264, 312]	[0.73, 0.84]	$\pm$ 48	[216, 288]	[0.60, 0.80]	$\pm$ 24

Conclusion

As can be seen from the table. 2, the reference and the restored bruises' age coincide with a sufficiently high degree of confidence, and the error in restoring decision classes can be reduced to 1 day. The dependence of the relative sizes of segments of multispectral images on the prescription of the appearance of superficial damage of human soft tissues using their processing with the help of fuzzy logic was experimentally revealed. In addition, it allowed to take into account the spectral parameters of intact skin and to identify surface damage on its background. In determining the prescription of superficial damage using fuzzy logic and image segmentation, the patient's personal data are also taken into account, namely: age, gender, height-weight ratio, etc. The developed method and tool are implemented in the Vinnytsia Regional Bureau of Forensic Medical Examination and in the educational and methodological process of the Vinnytsia National Medical University Pirogov at the Department of Pathological Anatomy, Forensic Medicine and Law (Vinnytsia, Ukraine).

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REFERENCES

[1] Mitryasova, O., Pohrebennyk, V., Cygnar, M., Sopilnyak, I. Environmental natural water quality assessment by method of correlation analysis. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, *SGEM,* 2, (2016), 317-324.

[2] Kvaternyuk S., Pohrebennyk V., Petruk R., Kochanek A., Kvaternyuk O. Multispectral television measurements of parameters of natural biological media, *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, 17 (51), (2017), 689-696.

[3] Petruk V., Kvaternyuk S., Kvaternyuk O., Mokanyuk O., Petruk R. et al., Assessment of the validity of the diagnosis of damage of tissues by multispectral method using neural network, *Przeglad elektrotechniczny*, vol. 93, no. 5, (2017), 106-109.

[4] Kvaternuk S., Petruk V., Kvaternuk O., Mokyanuk O., Kotyra A., Kozbakova A., Mathematical modeling of change in color coordinates of superficial injuries of human soft tissues for forensic medicine, *Information Technology in Medical Diagnostics II*, W. Wojcik, S. Pavlov, M. Kolimoldayev, Eds.. London, CRC Press, (2019), 67-76.

[5] Kvaterniuk S., Kvaterniuk O., Petruk V., H. Rakytyanska H. et al., 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*, (2019),11176.

[6] Martsenyuk V., Petruk V., Kvaternyuk, S., Pohrebennyk V., Bezusiak, Y., Petruk, R., Klos-Witkowska, A. Multispectral control of water bodies for biological diversity with the index of phytoplankton, *International Conference on Control, Automation and Systems*, № 7832429, (2016), 988-993.

[7] Capper C., The language of forensic medicine: the meaning of some terms employed, *Med. Sci. Law*, 41(2001), 256-259.

[8] Bariciak E.D., Plint A.C., Gaboury I., Bennett S., Dating of bruises in children: an assessment of physician accuracy, *Pediatrics*, 112, (2003), 804-807.

[9] Langlois N.E.I., Gresham G.A., The ageing of bruises: a review and study of the colour changes with time, *Forensic. Sci. Int*, 50, (1991), 227-238,.

[10] Hughes V.K., Ellis P.S., Langlois N.E.I., The perception of yellow in bruises, *J. Clin. Forensic. Med*, 11, (2004), 257-259,

[11] Munang L.A., Leonard P.A., Mok J. Y., Lack of agreement on colour description between clinicians examining childhood bruising, *J. Clin. Forensic. Med*, vol. 9. (2002), 171-174,.

[12] Zwart A., Buursma A, van Kampen E.J., Zijlstra W.G., Multicomponent analysis of hemoglobin derivatives with reversed-optics spectrophotometer, *Clin Chem*, 30, (1984), 3.

[13] Steinberg M.H. et al., *Disorders of Hemoglobin: Genetics, Pathophysiology, and Clinical Management*, 2nd edition, Cambridge : University Press, (2009).

[14] Rotshtein A.,. Rakytyanska H., Fuzzy Evidence in Identification, Forecasting and Diagnosis, *Studies in Fuzziness and Soft Computing,* Heidelberg, Germany: Springer, (2012).

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

[16] Rotshtein A., Shtovba S., Chernovolik G., Petruk V., Processing of optical information for medical decision making support systems by intelligent techniques, *Proceedings of SPIE*, 4425. (2001), 142-147.