Vasyl PETRUK[1], Sergii KVATERNYUK[1], Olena KVATERNYUK[2], Olexander MOKANYUK[3], Roman PETRUK[1], Svietlana VRAYSOVA[4], Konrad GROMASZEK[4], Saule LUGANSKAYA[4]

Vinnytsia National Technical Univ (1), Vinnytsia Humanitarian Pedagogical College (2), Vinnytsia National Medical Univ. (3), Lublin University of Technology (4)

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Assessment of the validity of the diagnosis of damage of tissues by multispectral method using neural network

***Abstract**. In this paper is the expert system designed and analysed for diagnostic decision support solutions in the study of surface damage of tissues by using multispectral method and neural network to process the results. We have developed specialized software for administration personal data of patients in forensic examination of biological tissues of human skin and combination of data in common database with digital photos injuries. The researchers analyzed the operating parameters of a diagnostic test to assess the diagnostic accuracy of surface damage biological tissues based on advanced of multispectral method.*

***Streszczenie.** W artykule opisano projekt I analizę systemu eksperckiego do wspierania decyzji przy badaniu uszkodzeń powierzchni tkanek z użyciem metod wielospektralnych i sieci neuronowych. Zostało opracowane specjalistyczne oprogramowanie do zarządzanie danymi pacjentów w badaniach sądowych skóry ludzkiej i kombinacji we wspólnej bazie danych cyfrowych fotografii ran. Zbadane zostały parametry operacyjne testów diagnostycznych w celu oszacowania ich dokładności oceny uszkodzeń tkanek metodą multispektralną. (**Ocena poprawności diagnostyki uszkodzeń tkanek metodą multispektralną z użyciem sieci neuronowych**).*

Keywords: multispectral image, biological tissue, forensic examination.
Słowa kluczowe: obraz multispektralny, tkanki, badania sądowe.

Introduction

Advanced methods of digital colorimetry and multispectral images of the surface damage of tissues in forensic medicine allow to register the skin damage of biological tissue forensic expert and use the findings as an evidence base [1, 2]. Specialized software allows you to define the image histogram of pathological skin lesion of biological tissue by mechanical blunt object. The resulting histogram biomedical together with other patient parameters is input to the expert system to support the selection of the diagnosis. Thus, the diagnostic tool allows you to formalize the known methods of visual expert evaluation of the term damage of human skin of biological tissue due to injury, it is necessary to reduce the subjectivity of the research in the forensic diagnosis.

Relevance of the work caused by necessity to improve the accuracy of diagnosis of superficial lesions of human skin tissues with regard to their optical and physical parameters by improving the method of digital colorimetry and multispectral images.

The goal of the research is the development and analysis of the expert system of diagnostic decision support solutions in the investigation of surface damage of biological tissues by using a neural network to process the results and analysis of the parameters of diagnostic validity.

Experimental studies of changes of the relative sizes of areas of surface damage

Experimental studies of changes in the relative sizes of areas of surface damage from the appearance of the time conducted at patient group – students of the Vinnitsa National Medical University during practical lessons on discipline "Forensic medicine". In experiments were investigated superficial soft tissue injury received during household injuries by blunt objects. Fig. 1 shows the surface damage zone, which differ in structure and concentration of degradation product of hemoglobin.

Considering the differences in the concentrations of hemoglobin degradation product even within a single surface damage, the image of the surface damage will always be a few areas that can be identified using multispectral parameters. The absorption index of the dermis layer with surface damage depends on the parameters of a bruise:

$$\mu'_{a3-7}(\lambda) = f_{blood}\mu_{\grave{a},blood}(\lambda) + f_{bruise}\mu_{\grave{a},bruise}(\lambda) + \\ +(1 - f_{blood} - f_{bruise})\mu_{a,bd}(\lambda), \quad (1)$$

where f_{blood} – volume content blood into vessels,
f_{bruise} – volume content of hemorrhage in dermis,
$\mu_{\grave{a},blood}(\lambda)$ – absorption index of blood in vessels,
$\mu_{a,bd}(\lambda)$ – absorption index of bleeding dermis.

At the same time, the absorption index of hemorrhage in the dermis is determined by the molar concentrations and molar absorption index of blood hemoglobin degradation products, that is in hemorrhage:

$$\mu_{\grave{a},bruise}(\lambda) = C_{HbO_2}\mu_a^{HbO_2}(\lambda) + C_{Hb}\mu_a^{Hb}(\lambda) + C_{MetHb}\mu_a^{MetHb}(\lambda) + \\ C_{biliverdin}\mu_a^{biliverdin}(\lambda) + C_{bilirubin}\mu_a^{bilirubin}(\lambda), \quad (2)$$

where C_{HbO_2}, C_{Hb}, C_{MetHb}, $C_{biliverdin}$, $C_{bilirubin}$ – molar concentration of oxyhemoglobin, reduced hemoglobin, methemoglobin, bilirubin and biliverdin,
$\mu_a^{HbO_2}(\lambda)$, $\mu_a^{Hb}(\lambda)$, $\mu_a^{MetHb}(\lambda)$, $\mu_a^{biliverdin}(\lambda)$, $\mu_a^{bilirubin}(\lambda)$ – molar absorption index of oxyhemoglobin, reduced hemoglobin, methemoglobin, bilirubin and biliverdin.

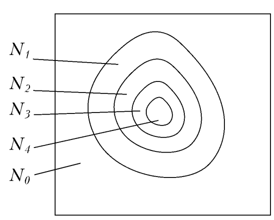

Fig. 1. Surface damage zone of the human skin after mechanical injury that have different concentrations of hemoglobin degradation products

In processing the results of experimental studies changes in the relative sizes of the zones of damage to a large number of patients and their averaging received such a dependence of the relative sizes of areas of surface damage (Fig. 2). We carry out an approximation of these plots with a linear regression and Gauss function in Mathcad 13.0:

(3) $f_{bruise\ i}(T) = 100 \cdot a_i \cdot \exp\left(\frac{-(T-b_i)}{2 \cdot c_i^2}\right),$

where a_i, b_i, c_i - coefficients obtained from nonlinear regression parameters of function $f_{bruise\ i}(T)$ that allow minimum mean square error description of this feature experimental research results change the relative sizes of the zones.

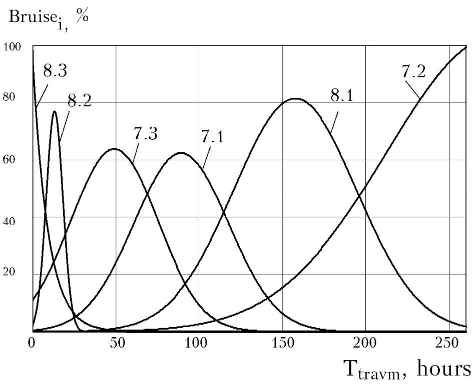

Fig. 2. Average dependence of relative sizes zones of surface damage

The functional dependence for determining the time of occurrence of surface damage can be written as follows:

$$(4)\quad f_j\left(T \in (t_j, t_{j+1})\right) = \sum_{i=1}^{i\_max} \frac{k_i}{100} \cdot f_{bruise\ i}(T) = \\ = \sum_{i=1}^{i\_max} k_i \cdot a_i \cdot \exp\left(\frac{-(T-b_i)}{2 \cdot c_i^2}\right),$$

where k_i – weighting factors.

At the same time occurrence of surface damage determined by membership function limitation to a specific interval, that will be the maximum, and will be determined according to the rule:

$$(5)\ T = \begin{cases} \text{from } 0 \text{ to } t_1, \text{if } f_0\left(T \in (0,t_1)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_1 \text{ to } t_2, \text{if } f_1\left(T \in (t_1,t_2)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_2 \text{ to } t_3, \text{ if } f_2\left(T \in (t_2,t_3)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_3 \text{ to } t_4, \text{if } f_3\left(T \in (t_3,t_4)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_4 \text{ to } t_5, \text{if } f_4\left(T \in (t_4,t_5)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_5 \text{ to } t_6, \text{if } f_6\left(T \in (t_5,t_6)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_6 \text{ to } t_7, \text{if } f_7\left(T \in (t_6,t_7)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{from } t_7 \text{ to } t_8, \text{if } f_2\left(T \in (t_7,t_8)\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right); \\ \text{over } t_8, \text{if} f_8\left(T > t_8\right) = \max\left(f_j\left(T \in (t_j, t_{j+1})\right)\right). \end{cases}$$

Obtained rule for determining the time of occurrence of surface damage to a certain interval actually corresponds to the principle of the neural network, which are input to the relative sizes of the surface damage zones.

Expert diagnostic system in the investigation of surface damage of biological tissues

To diagnose the damage of tissues in forensic medicine developed by an expert system to determine the time elapsed from the time of injury with a blunt object on the basis of the processing results of multispectral parameters of the damaged area in the form of a bar graph $Bruise_{j\%}$ with the relative number of pixels occupied by elements of the image with the coordinates closest to each of the elements of the sample scale and other biomedical parameters from the patient questionnaires, which are variables corresponding to the plural types of sets of a fixed number of elements:

Age: 0-20 years ($x1_1$), 20-30 years ($x1_2$), 30-40 years ($x1_3$), 40-50 years ($x1_4$), 50-60 years ($x1_5$), 60 years ($x1_6$) $X1 = \{x1_1, x1_2, \ldots, x1_6\}$;

Gender: male ($x2_1$), female ($x2_2$) $X2 = \{x2_1, x2_2\}$;

Rees-Eysenck Index: less 96 - pyknic type ($x3_1$), from 96 to 106 normostenic type ($x3_2$), more than 106 asthenic type ($x3_3$) $X3 = \{x3_1, x3_2, x3_3\}$;

Object of examination: a living person ($x4_1$), corpse ($x4_2$) $X4 = \{x4_1, x4_2\}$;

Location: head, neck ($x5_1$), shoulder girdle ($x5_2$), trunk ($x5_3$), thigh, buttock ($x5_4$), forearm, wrist ($x5_5$), shin, foot ($x5_6$) $X5 = \{x5_1, x5_2, \ldots, x5_6\}$;

Shape: round ($x6_1$), oval ($x6_2$), irregular oval ($x6_3$) $X6 = \{x6_1, x6_2, x6_3\}$.

At the output of the expert system is to generate diagnostic solution in the form of a length of time that has elapsed since the time of injury with a blunt object, which is part of the following set:

Duration: until 1 hour (t_1), from 1 to 3 hours (t_2), from 6 to 12 hours (t_3), from 12 to 24 hours (t_4), from 24 to 48 hours (t_5), from 48 to 72 hours (t_6), from 72 to 96 hours (t_7), more than 96 hours (t_8) $T = \{t_1, t_2, \ldots, t_8\}$.

Developed specialized software for the input of personal data of patients in forensic medical examination of human skin of biological tissues and combinations in a single database with digital photographs of damage.

To build an expert system of diagnostic decision support solutions for the length of time elapsed since the injury with a blunt object to the forensic examination with the help of neural networks are using packet STATISTACA 6.0 Neural Networks.

We examine the possibility of using the network architecture for the construction of a neural network on the basis of:

- multilayer perceptron with one hidden layer – 1 (Figure 3);
- multilayer perceptron with two hidden layers – 2;
- probabilistic neural network – 3;
- network with radial basis function – 4.

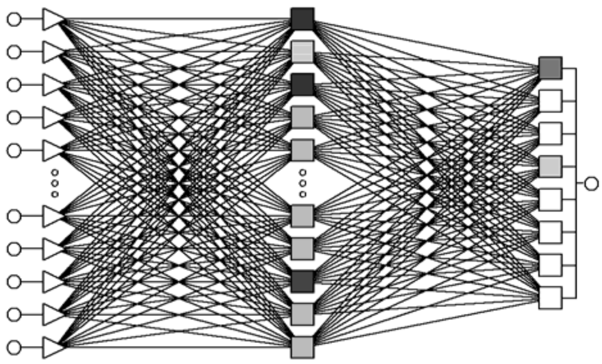

Fig. 3. Architecture of neural network based on multilayer perceptron with one hidden layer

For training the neural network are using data length of time which has been determined forensic expert on the basis of a survey of patients $T_{in} = \{t_1, t_2, \ldots, t_8\}$. After learning of neural networks for 500 iterations following results their performance and operation errors are were obtained (Table 1).

Table 1. Performance and error of neural networks

Architecture	Perform. learning	Perform. control	Perform. test.	Error training, %	Error control, %	Error test, %
1	0.986111	0.485714	0.371429	0.372299	5.978848	6.183768
2	0.986111	0.485714	0.400000	0.153704	5.539583	5.836819
3	0.722222	0.371429	0.314286	0.203663	0.2883422	3.082088
4	0.555556	0.428571	0.285714	0.255504	0.2848522	3.031888

Assessment of the validity of medical diagnosis of biological tissues damage

We analyze the diagnostic accuracy of surface of damage of biological tissues by using a testing data set: T_{in} – the length of time that was calculated forensic expert on the basis of a survey of patients (used as a true time value), T_{out} – the length of time at the output of of the expert system. T_{in} and T_{out} are elements of the set T = { t_1, t_2,…, t_8}.

As a result of the diagnosis is necessary to determine the length of time exceeds a certain value T_{const}. In this case, in the diagnosis of such variants are possible:

$$(6)\quad \begin{cases} P_1 = 1 \ \ if \ \ T_{in} \geq T_{const}, \ \ else \ \ P_1 = 0, \\ P_2 = 1 \ \ if \ \ T_{in} < T_{const}, \ \ else \ \ P_2 = 0, \\ P_3 = 1 \ \ if \ \ T_{out} \geq T_{const}, \ \ else \ \ P_3 = 0, \\ P_4 = 1 \ \ if \ \ T_{out} < T_{const}, \ \ else \ \ P_4 = 0, \end{cases}$$

where P_1, P_2 – variables from sets {0;1}, corresponding to the actual value of the duration T_{in},

P_3, P_4 – variables from sets {0;1}, corresponding value of the duration at the output of the expert system.

Thus it is possible to calculate the variables A, B, C, D corresponding to all the possible events in the diagnostic process:

$$(7)\quad \begin{cases} A = 1 \ \ if \ \left((P_1 = 1) \ \wedge \ (P_3 = 1) \right), \ \ else \ \ A = 0, \\ B = 1 \ \ if \ \left((P_2 = 1) \ \wedge \ (P_3 = 1) \right), \ \ else \ \ B = 0, \\ C = 1 \ \ if \ \left((P_1 = 1) \ \wedge \ (P_4 = 1) \right), \ \ else \ \ C = 0, \\ D = 1 \ \ if \ \left((P_2 = 1) \ \wedge \ (P_4 = 1) \right), \ \ else \ \ D = 0, \end{cases}$$

where A, B, C, D – variables from sets {0;1},

A – corresponds to an event when in the process of diagnosing get a true positive result (a result of diagnosing a positive result of diagnosis and the true value was also positive)

B – corresponds to an event when in the process of diagnosis of a false positive result is obtained (as a result of diagnosing a positive result of diagnosis and the actual value of the sign was negative),

C – corresponds to an event when in the process of diagnosing received a false-negative result (a result of the diagnosis of a negative result of diagnosis and the actual value of the sign was positive)

D – corresponds to an event when in the process of diagnosing get a true-negative result (a result of diagnosing a negative result of diagnosis and the actual value of the flag was also negative).

We count variables P_1, P_2, P_3, P_4 and, accordingly, A, B, C, D by the formulas (1), (2) testing for a set of data. Event analysis results for medical diagnosing of damage of biological tissues are given in Table 2.

Accordingly, the amount of each type of event for medical diagnosis will $a = \sum_{i=0}^{n} A_i$, $b = \sum_{i=0}^{n} B_i$, $c = \sum_{i=0}^{n} C_i$, $d = \sum_{i=0}^{n} D_i$. The obtained values a, b, c, d are making in the contingency table (2x2 contingency table) to compare the two groups (Table 3).

Based on the data calculates the validity of a diagnostic test. Predictive validity - information about the procedure (test), which characterizes the degree of accuracy and validity of judgments about the quality of diagnostics on its result after a certain time after the measurement. The present value (degree of confidence) the research determined the sensitivity and specificity parameters. In some cases, the practical expedient (high specificity) excessive sensitivity, which is associated with an increase in the parameter of hyperdiagnostics. Otherwise, the sensitivity increases with decreasing parameter hypodiagnostics.

Table 2. Analysis of events in the diagnosis of superficial damage of biological tissues

N	T_{in}	T_{out}	Actual value		Diagnostic results		A	B	C	D
			$P_1(+)$	$P_2(-)$	$P_3(+)$	$P_4(-)$				
1	1	1	0	1	0	1	0	0	0	1
2	1	1	0	1	0	1	0	0	0	1
3	5	5	1	0	1	0	1	0	0	0
4	2	4	0	1	1	0	0	1	0	0
5	8	8	1	0	1	0	1	0	0	0
6	7	2	1	0	0	1	0	0	1	0
…										
583	8	8	1	0	1	0	1	0	0	0

Table 3. Comparison of the diagnostic results and the actual characteristic values

Results of diagnosing	Actual value		Total
	Positive value (+)	Negative value (-)	
Positive results of diagnosing (+)	true positive (TP) *a* = 350	false positive (FP) *b* = 11	*a* + *b* = 361
Negative results of diagnosing (-)	false negative (FN) *c* = 8	true negative (TN) *d* = 214	*c* + *d* = 222
Total	*a* + *c* = 358	*b* + *d* = 225	a + b + c + d=583

On the basis of a comparative table to determine the operating parameters of a diagnostic test [3, 4, 5, 6]:

- diagnostic sensitivity (sensitivity or true positive rate (*TPR*)), the percentage of people with a positive diagnosis among people with a real positive value

$$(8)\quad TPR = \alpha/(a+c) = 350/(350+8) = 0.978 ;$$

- diagnostic specificity (specificity (*SPC*) or true negative rate), the proportion of patients with negative results of diagnosis among individuals with this negative trait value

$$(9)\quad SPC = d/(d+b) = 214/(214+11) = 0.951 ;$$

- diagnostic efficiency, average between *TPR* and *SPC*

$$(10)\quad E = (TPR + SPC)/2 = (0.978 + 0.951)/2 = 0.964 ;$$

- positive predictive value of the test (precision or positive predictive value (*PPV*)) – the probability of having a positive characteristic value with a positive result of diagnosis

$$(11)\quad PPV = a/(a+b) = 350/(350+11) = 0.97 ;$$

- negative predictive value of the test (negative predictive value (*NPV*)) – the probability of having a negative characteristic value with a negative result of diagnosis:

$$(12)\quad NPV = d/(c+d) = 214/(8+214) = 0.964 ;$$

- general statistical validity (validity or accuracy (ACC))

$$(13)\quad ACC = (a+d)/(a+b+c+d) = 0.967 ;$$

- F1 score:

$$(14)\quad F1 = 2a/(2a+b+c) = 2 \cdot 350/(2 \cdot 350 + 11 + 8) = 0.973 .$$

The probability of a type I error, the rate of hyperdiagnostics (α errors, type I error probability, fall-out or false positive rate (FPR)):

(15) $\alpha = b/(b+d) = 11/(11+214) = 0.049$.

The probability of type II errors, indicator hypodiagnostics (β errors, type II errors probability, false negative rate (FNR)):

(16) $\beta = c/(a+c) = 8/(350+8) = 0.022$.

Adequacy:

(17) $D = 1 - \alpha - \beta = 1 - 0.049 - 0.022 = 0.029$

Likelihood ratio positive:

(18) $LR_{+} = TPR/(1 - SPC) = 20$

Likelihood ratio negative:

(19) $LR_{-} = (1 - TPR)/SPC = 0.023$

Diagnostic odds ratio (DOR):

(20) $DOR = LR_{+}/LR_{-} = 20/0.023 = 869.57$

Let us compare the results of evaluation of the validity of determining the time of occurrence of surface damage of human soft tissue to develop methods and tools with the validity, which provide traditional methods. For comparison the reliability different methods, we will conduct research for the same group of recipients that has been used to assess the validity of this method and means. The forensic traditionally used a visual version of a colorimetric method for determining the time of occurrence of surface damage, where the expert subjectively visually compares the color damage with the colors from colors scale samples and determine the closest color scale element. For each of the elements of scale of colors samples known accurate color coordinates, which allows to determine the time of occurrence of damage. When using a visual colorimetric method a significant influence on determining the time of occurrence of the biological tissue lesions exercise methodical errors related to the subjective determination of the color of the surface lesions. When using a visual colorimetric method and comparing the results of the study and the actual value is obtained a = 320, b = 53, c = 34, d = 176.

Table 4. Operating parameters to the research

Parameter	Visual colorimetric method	Spectro-photometric method	The developed method
Sensitivity (true positive rate)	0.904	0.958	0.978
Specificity (true negative rate)	0.769	0.912	0.951
Efficiency	0.836	0.935	0.964
Validity	0.851	0.940	0.967
Type I error probability (false positive rate)	0.231	0.088	0.049
Type II errors probability (false negative rate)	0.096	0.042	0.022
Adequacy	0.673	0.870	0.929

Color coordinates of surface injuries as may be determined by using spectrophotometric variant colorimetric method. For the measurement of spectral characteristics of the diffuse reflectance of the surface lesions using a spectrophotometer SF-18, followed by the calculation of color coordinates in CIEXYZ and CIELAB system using a personal computer. Based on the calculated color coordinates in the CIELAB system is determined by the time appearance of surface injuries. When using spectrophotometric colorimetric method should be noted that the coordinates of the color is determined by averaging for the surface area of lesions, adjacent to the working aperture of primary measuring converter. When using colorimetric spectrophotometric method and comparing the results of the research and the actual value is obtained a = 340, b = 20, c = 15, d = 208. For conventional methods of determining the time appearance of injuries must be calculated the operating parameters of the study by the formulas (1) - (16) and determine the validity. The main operating parameters of the study with the help of this method, as well as traditional methods are summarized in Table 4.

Conclusions

The paper designed and analyzed the work of the expert system of diagnostic decision support solutions in the investigation of surface damage of biological tissues by using a neural network to process the results. It checked the possibility of using a neural network architecture based on a multilayer perceptron with one hidden layer, multi-layer perceptron with a two hidden layers, probabilistic neural networks and networks with radial basis function. After learning of neural networks for 500 iterations based on the results of test sequences studied performance and operation errors. The smallest error 0.288% has given a probabilistic neural network. We analyze the operating parameters of diagnostic test to assess the diagnostic accuracy of surface of damage of biological tissues. Obtained performance diagnostic sensitivity 0.978, diagnostic specificity 0.951, general statistical validity 0.967, sufficient for the use of the developed diagnostic tools for the needs of forensic medical examination.

***Authors**: dr Vasyl Petruk, Vinnytsia National Technical Univ., Khmelnytske Shose, 95, Vinnytsia, 21021, Ukraine; dr Sergii Kvaternyuk, Vinnytsia National Technical Univ., Khmelnytske Shose, 95, Vinnytsia, 21021, Ukraine; dr Olena Kvaternyuk, Vinnytsia Humanitarian Pedagogical College, Nagirna street, 13, Vinnytsia, Ukraine; dr Olexander Mokanyuk, Vinnytsia National Medical Univ., Pirogov str., 56, Vinnytsia, 21018, Ukraine; Roman Petruk, Vinnytsia National Technical Univ., Khmelnytske Shose, 95, Vinnytsia, 21021, Ukraine; mgr inż. Svietlana Vraysova, mgr inż. Saule Luganskaya, dr inż. Konrad Gromaszek Instytut Elektroniki i Technik Informacyjnych, Nadbystrzycka 38A, 20-618 Lublin, e-mail: k.gromaszek@pollub.pl;*

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