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INTELLIGENT SYSTEM OF COMPRESSION AND RECOGNITION OF IMAGES DESIGNED FOR LASER BEAM PROFILING

Actuality of elaboration of new approaches to the solution of the problem of laser beams profiling within the context of development of optoelectronic information technologies and enhancement of economic efficiency is substantiated. On the basis of methodological analysis of existing technologies and trends of image processing information system development the method of adaptive processing and compression of color spot images is suggested.

By the results of computer modeling program realization of intelligent system of compression and neuro-networking recognition of spot images of laser beams is performed.

Key words: *intelligent systems, system of laser beams profiling, images recognition, real-time image processing.*

Introduction

At present stage of development of science and engineering mutual interrelation, integration of various branches of engineering, adaptation of approaches and methods inherent to certain spheres for solution of problems is observed: among priority tasks put forward by the state, in the context of other global problems, important place is taken by innovation projects, including realization of modern technological processes, introduction of laser equipment based on variouse computer technologies. That is why, the range of problems, connected with the investigation of the principles of parallelism, intelligent structures, nano- and optoinformation technologies on hardware and software level remains very actual [1, 2].

Laser technologies are applied for machining of materials, in medical sphere, measuring engineering, in sensor system, system of image formation, laser optic, etc. Leading companies, operating in this branch, are EUROlaser, Rofin-Sinar Laser, Laserline GmbH, Laser Pluss AG, Gamma Scientific, Photonics Products, particular in Ukraine – "UkrH…" [3].

Wide application of lasers is due to their specific features. Temporal nature of lasers beam allows its changes from infinite wave to very short pulse. Coherence of laser allows it to move along the narrow beam with minor and definite divergence. It enables the user to define accurately the area illuminated by the laser beam.

Due to coherence laser beam can be focused into very small saturated spot in highly concentrated area. Such concentration makes laser beam useful for application in physics, chemistry, medicine, in various engineering applications [4, 5]. However, propagating in the atmosphere or in certain medium, light beam can be subjected to distortions, which are evaluated and compensated on the base of corresponding quantitative data. Accordingly, devices, using lasers, require high level of automatic control over the laser beam for correct realization of the task.

The investigation of the processes of beam profile formation, according to which the intensity of laser beam changes along cross-section, is vey actual [4, 6].

By the results of analysis of laser beam profile, that can be conveniently presented in the form of spot image with spectral division of colors according to the intensity of emission, it is possible to make indirect conclusion regarding technical state of the laser. Its technical state directly influences performance and correctness of laser system operation. Thus, the problem of laser beams profiling is urgent and economically expedient.

Analogous research are performed by scientific schools in different countries of CIS (for instance, Scientific-Industrial group "Astroshysics", Moscow, Russia).

Much attention is paid to this direction of research in the USA. This fact is proved by analogous investigations and hardware-software developments performed by such leading American corporation as Photo Inc. (San Jose, USA), Spiricon Inc. (Logan, Utah, USA), Coherent Auburn Group (Auburn, California, USA).

In Ukraine these problems are investigated mainly by scientific-research institutions, such as Scientific-Research Institute of Laser engineering and technology, of National Technical University "KPI", Lashkariev Institute of Physics of Semiconductors of National Academy of Science of Ukraine, etc. [3, 4, 6].

Problem set-up

As the profile of laser beam changes, then there appears the necessity to store in the memory of information-measuring system large sequence of spotted multicolor images for their further processing and recognition. That is why, images must be presented in optimal form: without losing key information, but at the same time occupy sufficient volume of memory required for system operation.

Aim of research

The aim of the given research is the enhancement of operation rate and optimization of structural functional organization of neural network and its computational complexity, as well as recognition of spotted images of laser beam profile by means of development of intelligent system for further diagnosis of the technical state of laser in real time.

Description of the method of compression and recognition of spotted images

Among directions aimed at study of artificial intelligence for the solution of complex problems of image recognition and their classification, according signs, the most efficient being neuronetworking recognition technologies [2,7,10]. The first stage of neuronetworking recognition is formalization of the problem and construction of minimal input vector, containing necessary information about the object of recognition. Input data for such a problem is the sequence of frames of dynamic extended videoroute of laser beam, presented in the form of 8-bits "BMP"-files in color model of RGB or greyscale of 128x128 points dimensionality, for instance, as it is shown in Fig.1. Without compression procedure, for description of the given dimensionality, we would require 128x128x3 = 49152 bytes of memory. Allocation of such volume of memory per each frame considerably reduces the processing efficiency while further advance to the inputs of neuronetworking structure.

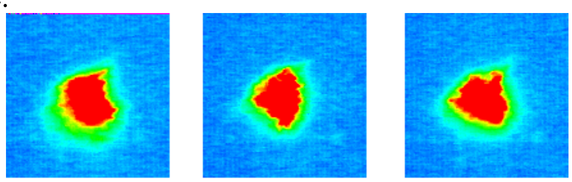


Fig. 1. Examples of input spotted images

That is why, the following sequence of operations over input spotted image was suggested. This sequence is performed by intelligent system [1, 7, 8].

1. Preprocessing of the image for further recognition.
   1.1 Allocation of the informative portion of the image ("Smart Crop")
   1.2 Topological analysis of the obtained operation area (segmentation)
   1.3 Averaging of color in each area of segmentation.
2. Recognition procedure.

"Smart Crop" is intended for allocation of spotted image from background portion of the image for further analysis and provides the realization of the following steps :

Determination of the center of highest intensity applying the method of defining the mass center of the image [8].

Using 2D orthogonal system of coordinates allows to obtain the following expressions for determination of each coordinate:

$$x=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}(\omega_{ij}-\omega_{bg})^k}{\sum_{i=1}^{n}\sum_{j=1}^{m}(\omega_{ij}-\omega_{bg})^k}, \qquad y=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} y_{ij}(\omega_{ij}-\omega_{bg})^k}{\sum_{i=1}^{n}\sum_{j=1}^{m}(\omega_{ij}-\omega_{bg})^k}, \tag{1}$$

where x –is the abscissa of the center of maximum intensity; y – is the ordinate of highest intensity center; x_{ij} – is the abscissa of current pixel with the coordinates (i;j); y_{ij} – is the ordinate of current pixel with the coordinates (i;j); ω_{ij} – is weight coefficient of the current pixel (physical sense of which – intensity, brightness of the color); ω_{bg} – weight coefficient of the background, $\omega_{bg}\in[0;+\infty)$; k – is refinement coefficient (allocation) of brightness gradation.

If we take as the beginning of countdown upper left angle of the image, then the above-mentioned equation will have the following form:

$$x=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} i(\omega_{ij}-\omega_{bg})^k}{\sum_{i=1}^{n}\sum_{j=1}^{m}(\omega_{ij}-\omega_{bg})^k}, \qquad y=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} j(\omega_{ij}-\omega_{bg})^k}{\sum_{i=1}^{n}\sum_{j=1}^{m}(\omega_{ij}-\omega_{bg})^k}. \tag{2}$$

Further processing of the image is performed applying certain components of model “CIEXYZ” and “HSV (HSB)” taking into account their mutual correspondence and their correspondence with model “RGB”. In these 3-components color models the selection of main colors is due to peculiarities of perception physiology of color by retina of the human eye. Main feature of “XYZ” model is that any color, that is physically perceived by human being is presented only by positive values [5].

The developed intelligent system contains neural network (NN) that is the formalized model of biological network of neurons of human brain, that is why, it is expedient to use intermediate color models, constructed, taking into account visual abilities of human being.

For determination of color intensity of each pixel and background color on RGB-image it is necessary to allocate three components “r”, “g” and ”b” and carry out linear transformation in “XYZ” model by Y-component. For representation of colors in RGB model standard 4-byte type “COLORREF” is used in OS “WINDOWS”. While determination of any RGB color, the value of type variable as a rule is presented in hexadecimal form:

0x00bbggrr,

where rr, gg, bb – is the value of intensity of red, green and blue components of color.

Maximum value of color components is 0xFF.

For allocation of separate component of the color, it is necessary to perform bit-wise shift by corresponding number of digits.

$$R=\frac{0x00FF0000\ \&\ rgb}{65536*255}, \quad G=\frac{0x0000FF00\ \&\ rgb}{256*255}, \quad B=\frac{0x000000FF\ \&\ rgb}{255}. \tag{3}$$

Dimension Y of color model XYZ is relative brightness:

$$Y=0.2126*R+0.7152*G+0.0722*B. \tag{4}$$

Within the context of the problem of spotted images recognition for profiling of laser beams Hue component of “HSV (HSB)” color model is used, that corresponds to component Y of “XYZ” model and represents luminosity function, (luminosity function defines the value of coefficients, range of values being from 0 to 1 in corresponding components of “RGB” model proceding from the fact that green color influences greatly the perception of brightness by human eye, red color influences less, blue color influences least). As the levels of brightness of image spot of laser beam are presented by the colors of spectrum, then actual accuracy is defined by the following transformation:

$$\omega_{ij} = Y = 0.2126 * R + 0.7152 * G + 0.0722 * B, \qquad 0 \le \omega_{ij} \le 1. \tag{5}$$

While searching of weighted centre of maximum intensity all pixels of input square image are taken into account, that is why background pixels influence the definition of the centre and give error in resulting coordinates. That is why, for more accurate definition the adjustment coefficient (allocation coefficient) of brightness gradation in *k-th* power is used [5]

2. Allocation of the circumference points of maximum radius with the centre in the point of maximum intensity, inscribed in the square.

We define maximum radius of the circle with the centre in the point of maximum intensity, that can be inscribed in the square of 128x128 pixels and allocate it for further processing by the following expression:

$$R_{\max} = Min((w - x), x, (h - y), y), \tag{6}$$

where *w* and *h* are the width and height of the image correspondingly;

x – is the abscissa of the maximum intensity center; y – is the ordinate of maximum intensity center.

3. Adjustment of informative portion of the image, allocating the background color.

Adjustment is performed by means of iterative comparison of average color intensity in the circle between radii $R_{\max}$ and $R_{\max} - 2$, with ω_{bg} weight coefficient. While each iteration $R_{\max}$ decreases by 1 pixel, until the circle with the intensity higher than ω_{bg} is found. Then we cut out the spot with the current radius R.

After application of “Smart Crop” the dimension of operation image slightly changes, that is why the necessary volume of memory remains unsuitable for further advance at the inputs of neuronetworking structure.

That is why, in the given system segmentation (topological analysis) of the image with further averaging of segment color intensity is applied. Segmentation is known method that is used for initial analysis of images, but only “optimum” segmentation, to large extent, determines the correctness and efficiency of problem solution. Greater part of segmentation methods are developed for monochromic images, and as a rule, their adaptation for operation with color images does not yield expected result. Hence, development of segmentation methods for processing of color images is necessary for the problem where neuronetworking processing is applied [7].

Having analyzed large number of spotted images of single-mode laser routes (14 routes by 2044 images), areas on the image were classified according to the influence on the place of energy center location and general evaluation of spot “correctness”. The image is divided into 5 circles of intensity and 30 zones correspondingly (Fig. 2).

The radii of internal circles relatively the radius of allocated information part of the image are distributed in the following way:

$$R_0 < 0.4R;\ \ 0.4R \le R_1 < 0.6R;\ \ 0.6R \le R_2 < 0.7R;\ \ 0.4R \le R_3 < 0.9R;\ \ 0.9R \le R_4 \le R.$$

Central zone is the most important and must include part of the image with maximum intensity. The following circles are divided into different number of sectors in accordance with their numbers: the second circle is divided into 2^2 sectors, the third circle is divided into 2^3, the fourth circle is divided into 2^4 sectors.

The last circle is not divided into zones, as it is boundary between information portion of the image and background. Peripheral points in real image are subjected to fluctuations (this is valid for peripheral points of level and digital cuts of the image); that influences the form of spectral lines [8].

That is why, in this boundary area it is expedient to average intensity along the whole circle.

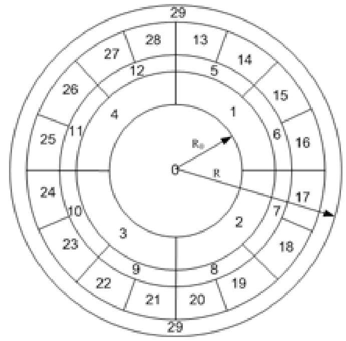
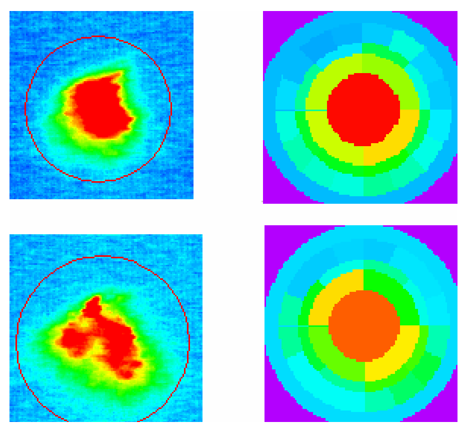


Fig. 2. Segmentation scheme of the spotted image of laser beam

For determination of zone number, where the processed pixel enters, we will define radius-vector of the point relatively the coordinate system with the center in the point of established energy center. The length of radius-vector will define the number of zone-circle. Further we will consider the point in polar coordinates and find angle φ-between polar axis and radius-vector and put its value into the positive plane.

If we know the number of zone-circle and polar angle φ, we define real number of the zone. Color intensity is averaged in each zone.

As a result of execution of all stages of preprocessing we obtain the image in compact form, acceptable for advance to the inputs of neuronetworking structure (Fig.3) For description of spotted image we need 30 bytes, as it is determined by 1-byte real value of average intensity of each of 30 zones.



a) b)

Fig. 3. Examples of spotted images:

a) initial images; b) image after preprocessing

Hence, application of intelligent preprocessing of the image provides economic usage of computer system memory resources and simplification of neural system structure as well as its operation rate [7,9]. It should be noted, that after preprocessing compressed image can not be restored in initial state, and this feature can be used for information protection in the network.

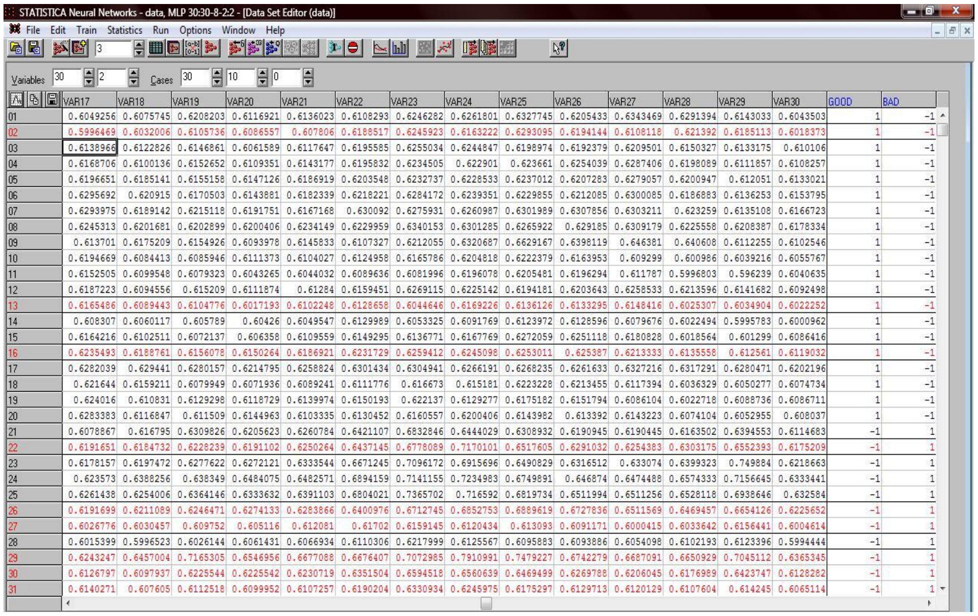
Computer-based modeling of neuronetworking system intended for recording of spotted images of laser beam profile

Computer simulation was performed in the package Statistica Neural Network 4.0 (SNN), company StatSoft, the package provides rapid and efficient methods of neuronetworking modeling and analysis [11].

Averaged values of color intensity in 30 zones, obtained as a result of preprocessing of spotted images were taken as initial data for neuronetworking model.

Input variables – fractional positive numbers with the accuracy up to 7 digits after comma, that can take values from 0 to 1. The fragment of data file with input data (data.sta) is presented in Fig.4. In this fragment VARI-VAR30 – are input values, GOOD and BAD – are reference outputs of neural system.

From one laser videoroute (2044 images) by the result of revealing of characteristic form of spots, depending on the level of distortion 40 image (20 “good” and 20 “bad”) were taken for neural network training. First of all it is necessary to determine the criterion of optimal complexity of the network - empirical method of generalization error evaluation.



	VAR17	VAR18	VAR19	VAR20	VAR21	VAR22	VAR23	VAR24	VAR25	VAR26	VAR27	VAR28	VAR29	VAR30	GOOD	BAD
01	0.6049256	0.6075745	0.6208203	0.6116921	0.6136023	0.6108293	0.6246282	0.6261801	0.6327745	0.6205433	0.6343469	0.6291394	0.6143033	0.6043503	1	-1
02	0.5996469	0.6032006	0.6105736	0.6086557	0.607806	0.6188517	0.6245923	0.6163222	0.6293095	0.6194144	0.6108118	0.621392	0.6185113	0.6018373	1	-1
03	0.6138966	0.6122826	0.6146861	0.6061589	0.6117647	0.6195585	0.6255034	0.6244847	0.6198974	0.6192379	0.6209501	0.6150327	0.6133175	0.610106	1	-1
04	0.6168706	0.6100136	0.6152652	0.6109351	0.6143177	0.6195832	0.6234505	0.622901	0.623661	0.6254039	0.6287406	0.6198089	0.6111857	0.6108257	1	-1
05	0.6196651	0.6185141	0.6155158	0.6147126	0.6186919	0.6203548	0.6232737	0.6228533	0.6237012	0.6207283	0.6279057	0.6200947	0.612051	0.6133021	1	-1
06	0.6295692	0.620915	0.6170503	0.6143881	0.6182339	0.6218221	0.6284172	0.6239351	0.6229855	0.6212085	0.6300085	0.6186883	0.6136253	0.6153795	1	-1
07	0.6293975	0.6189142	0.6215118	0.6191751	0.6167168	0.630092	0.6275931	0.6260987	0.6301989	0.6307856	0.6303211	0.623259	0.6135108	0.6166723	1	-1
08	0.6245313	0.6201681	0.6202899	0.6200406	0.6234149	0.6229959	0.6340153	0.6301285	0.6265922	0.629185	0.6309179	0.6225558	0.6208387	0.6178334	1	-1
09	0.613701	0.6175209	0.6154926	0.6093978	0.6145833	0.6107327	0.6212055	0.6320687	0.6629167	0.6398119	0.646381	0.640608	0.6112255	0.6102546	1	-1
10	0.6194669	0.6084413	0.6085946	0.6111373	0.6104027	0.6124958	0.6165786	0.6204818	0.6222379	0.6163953	0.609299	0.600986	0.6039216	0.6055767	1	-1
11	0.6152505	0.6099548	0.6079323	0.6043265	0.6044032	0.6089636	0.6081996	0.6196078	0.6205481	0.6196294	0.611787	0.5996803	0.596239	0.6040635	1	-1
12	0.6187223	0.6094556	0.615209	0.6111874	0.61284	0.6159451	0.6269115	0.6225142	0.6194181	0.6203643	0.6258533	0.6213596	0.6141682	0.6092498	1	-1
13	0.6165486	0.6089443	0.6104776	0.6017193	0.6102248	0.6128658	0.6044646	0.6169226	0.6136126	0.6133295	0.6148416	0.6025307	0.6034904	0.6022252	1	-1
14	0.608307	0.6060117	0.605789	0.60426	0.6049547	0.6129989	0.6053325	0.6091769	0.6123972	0.6128596	0.6079676	0.6022494	0.5995783	0.6000962	1	-1
15	0.6164216	0.6102511	0.6072137	0.606358	0.6109559	0.6149295	0.6136771	0.6167769	0.6272059	0.6251118	0.6180828	0.6018564	0.601299	0.6086416	1	-1
16	0.6235493	0.6188761	0.6156078	0.6150264	0.6186921	0.6231729	0.6259412	0.6245098	0.6253011	0.625387	0.6213333	0.6135558	0.612561	0.6119032	1	-1
17	0.6282039	0.629441	0.6280157	0.6214795	0.6258824	0.6301434	0.6304941	0.6266191	0.6268235	0.6261633	0.6327216	0.6317291	0.6280471	0.6202196	1	-1
18	0.621644	0.6159211	0.6079949	0.6071936	0.6089241	0.6111776	0.616673	0.615181	0.6223228	0.6213455	0.6117394	0.6036329	0.6050277	0.6074734	1	-1
19	0.624016	0.610831	0.6129298	0.6118729	0.6139974	0.6150193	0.622137	0.6129277	0.6175182	0.6151794	0.6086104	0.6022718	0.6088736	0.6086711	1	-1
20	0.6283383	0.6116847	0.611509	0.6144963	0.6103335	0.6130452	0.6160557	0.6200406	0.6143982	0.613392	0.6143223	0.6074104	0.6052955	0.608037	1	-1
21	0.6078867	0.616795	0.6309826	0.6205623	0.6260784	0.6421107	0.6832846	0.6444029	0.6308932	0.6190945	0.6190445	0.6163502	0.6394553	0.6114683	-1	1
22	0.6191651	0.6184732	0.6228239	0.6191102	0.6250264	0.6437145	0.6778089	0.7170101	0.6517605	0.6291032	0.6254383	0.6303175	0.6552393	0.6175209	-1	1
23	0.6178157	0.6197472	0.6277622	0.6272121	0.6333544	0.6671245	0.7096172	0.6915696	0.6490829	0.6316512	0.633074	0.6399323	0.749884	0.6218663	-1	1
24	0.623573	0.6388256	0.638349	0.6484075	0.6482571	0.6894159	0.7141155	0.7234983	0.6749891	0.646874	0.6474488	0.6574333	0.7156645	0.6333441	-1	1
25	0.6261438	0.6254006	0.6364146	0.6333632	0.6391103	0.6804021	0.7365702	0.716592	0.6819734	0.6511994	0.6511256	0.6528118	0.6938646	0.632584	-1	1
26	0.6191699	0.6211089	0.6246471	0.6274133	0.6283866	0.6400976	0.6712745	0.6852753	0.6889619	0.6727836	0.6511569	0.6469457	0.6654126	0.6225652	-1	1
27	0.6026776	0.6030457	0.609752	0.605116	0.612081	0.61702	0.6159145	0.6120434	0.613093	0.6091171	0.6000415	0.6033642	0.6156441	0.6004614	-1	1
28	0.6015399	0.5996523	0.6026144	0.6061431	0.6066934	0.6110306	0.6217999	0.6125567	0.6095883	0.6093886	0.6054098	0.6102193	0.6123396	0.5994444	-1	1
29	0.6243247	0.6457004	0.7165305	0.6546956	0.6677088	0.6676407	0.7072985	0.7910991	0.7479227	0.6742279	0.6687091	0.6650929	0.7045112	0.6365345	-1	1
30	0.6126797	0.6097937	0.6225544	0.6225542	0.6230719	0.6351504	0.6594518	0.6560639	0.6469499	0.6269788	0.6206045	0.6176989	0.6423747	0.6128282	-1	1
31	0.6140271	0.607605	0.6112518	0.6099952	0.6107257	0.6190204	0.6330934	0.6245975	0.6175297	0.6129713	0.6120129	0.6107604	0.614245	0.6065114	-1	1

Fig.4. Fragment of initial data array

Since generalization error is determined for data, that do not belong to the training set, the obvious solution of the problem is division of the data into 2 sets:

1. Training sample (30 sets of variables), that provides adjustment of weights in the process of training.

2. Control sample (10 sets of variables), that provides control of training process and helps to prevent retraining of the network [10].

The total number of constructed neural networks was 437, among these networks 10 best networks according to the parameter of error minimization in training and control samples were selected. In the given research only multilayer perceptrons were considered as basic and simple type of neural network for further realization.

Linear neural network and three-layered perceptrons with 30 neurons in input layer and 2 neurons in output layer but with different number of neurons in hidden layer were considered.

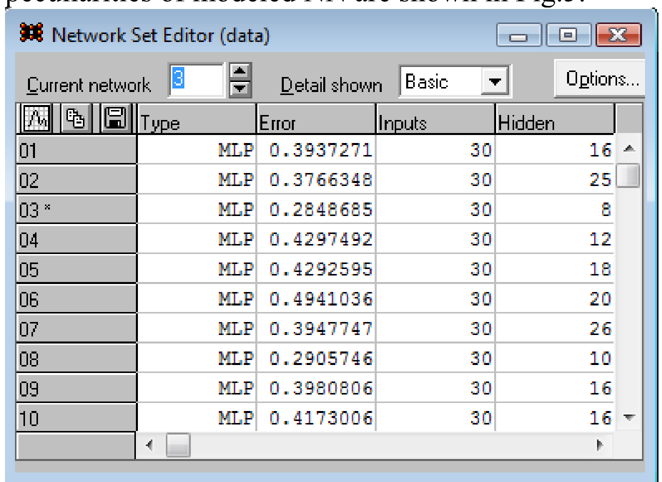
As it is known it is expedient to use two-layer perceptron in simple problems, since it has such drawbacks as, for instance, the problem of exclusive “or”, that is eliminated by means of adding one more third layer.

At the same time, the increase of the number of layers complicates the structure of the network and does not improve the results. For the input layer linear function of activation was used, for implicit layer non-linear function was used.

As non-linear activation function hyperbolic tangent (thx) was chosen as optimal from the point of view of further training by one of the group of methods of gradient descent. Hyperbolic tangent is differentiated function with symmetric relatively 0 area of determination [-1; 1], derivative of which is continuous and is expressed by this function. Besides as it is known from the literature, it is recommended to apply this activation function for classification of graphic objects [10].

One of the main parameters of NN and SNN efficiency evaluation is error of verification –

"V.Error". The amount of neurons in hidden layer was taken into consideration – their number must be minimal. Structural peculiarities of modeled NN are shown in Fig.5.



	Type	Error	Inputs	Hidden
01	MLP	0.3937271	30	16
02	MLP	0.3766348	30	25
03 *	MLP	0.2848685	30	8
04	MLP	0.4297492	30	12
05	MLP	0.4292595	30	18
06	MLP	0.4941036	30	20
07	MLP	0.3947747	30	26
08	MLP	0.2905746	30	10
09	MLP	0.3980806	30	16
10	MLP	0.4173006	30	16

Fig. 5. List if the best variants of structural organization of neural network.

After training it was revealed that three layered perceptron with 8 neurons in hidden layer, the structure of which is shown in Fig.6 functions best of all, and gives the least value of error 0,2848685.

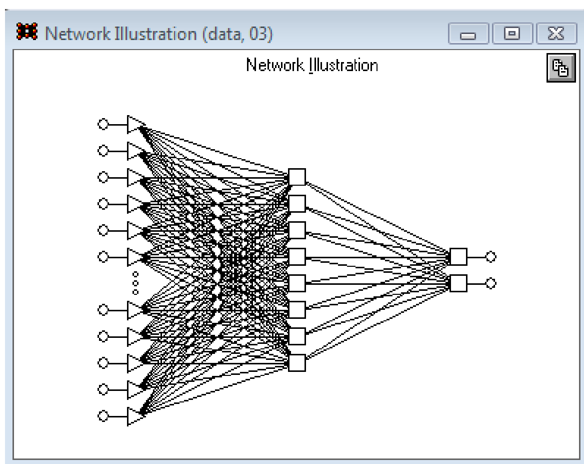


Fig. 6. Structural organization of NN selected for modeling

Neural network with eighth ordinal number (Fig.5) with 10 neurons in the hidden layer has perfect training parameters, but taking into account the complexity or arrangement by the number of neurons of the hidden layer, the best is neural network with third ordinal number (Fig.5).

Among 10 neurons, selected by the system automatically (Fig.5), the first, ninth and tenth, have 16 neurons in the hidden layer but differ by activation functions of each layer.

It was revealed, that minimum error is achieved while using hyperbolic tangent as activation function. The graph of error on training and control samples is shown in Fig.7.

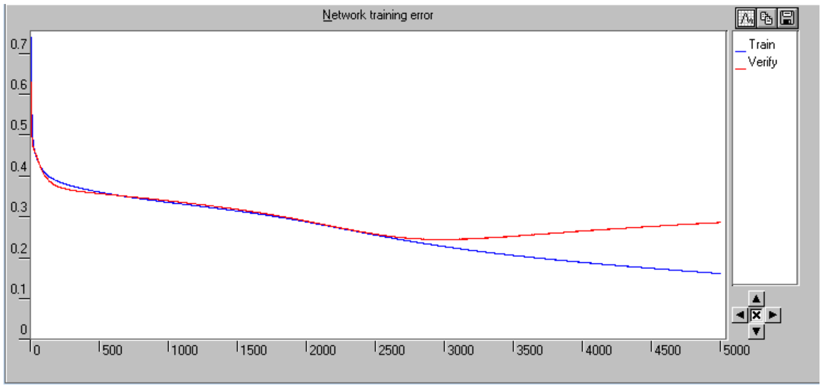
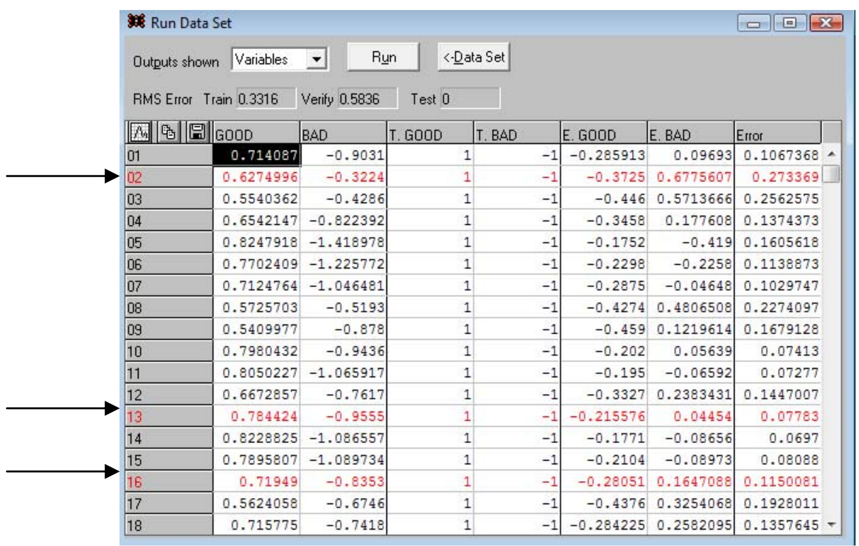


Fig.7. Graph of training errors and verification of neural network (NN) selected for modeling

Among six methods of training, presented in SNN (quasi-neuton, conjugate gradients, Levenberg-maccardt, rapid descent, back propagation of the error, delta-delta) the method of back propagation was chosen, taking into account the structure of neural network, function of activation and features of further program realization.

The required number of epochs (3000) and training rate (0.001) were selected experimentally to provide practical coincidence of errors graphs and avoid retraining. If the network is retrained, then the curve of error verification graph starts to grow after achiving the minimum. The lower the curve is, the better neural network functions.

Fig. 8 shows the results of recognition of spotted images of neural network that was selected for modeling.



	GOOD	BAD	T. GOOD	T. BAD	E. GOOD	E. BAD	Error
01	0.714087	-0.9031	1	-1	-0.285913	0.09693	0.1067368
02	0.6274996	-0.3224	1	-1	-0.3725	0.6775607	0.273369
03	0.5540362	-0.4286	1	-1	-0.446	0.5713666	0.2562575
04	0.6542147	-0.822392	1	-1	-0.3458	0.177608	0.1374373
05	0.8247918	-1.418978	1	-1	-0.1752	-0.419	0.1605618
06	0.7702409	-1.225772	1	-1	-0.2298	-0.2258	0.1138873
07	0.7124764	-1.046481	1	-1	-0.2875	-0.04648	0.1029747
08	0.5725703	-0.5193	1	-1	-0.4274	0.4806508	0.2274097
09	0.5409977	-0.878	1	-1	-0.459	0.1219614	0.1679128
10	0.7980432	-0.9436	1	-1	-0.202	0.05639	0.07413
11	0.8050227	-1.065917	1	-1	-0.195	-0.06592	0.07277
12	0.6672857	-0.7617	1	-1	-0.3327	0.2383431	0.1447007
13	0.784424	-0.9555	1	-1	-0.215576	0.04454	0.07783
14	0.8228825	-1.086557	1	-1	-0.1771	-0.08656	0.0697
15	0.7895807	-1.089734	1	-1	-0.2104	-0.08973	0.08088
16	0.71949	-0.8353	1	-1	-0.28051	0.1647088	0.1150081
17	0.5624058	-0.6746	1	-1	-0.4376	0.3254068	0.1928011
18	0.715775	-0.7418	1	-1	-0.284225	0.2582095	0.1357645

Fig. 8. Screen form of the results of images recognition by the network modeled in SNN

The arrow shows the vectors of control (verification) sample. Generalized results of recognition are presented in table 1.

Table 1

Generalized table of recognition results of modeled neural network (NN)

Type of the set	Number of the element	Correct recognition	Correct recognition	Non-correct recognition	Non-recognized
Training	33	29		1	0
Control	34	9		1	0

On the basis of computer simulation, intelligent system of neuronetworking recognition and classification of spotted images for preprocessing of laser beam profile characteristics was developed [12] structural functional diagram of the system in shown in Fig.9. Screen version of program realization is shown in Fig.10.

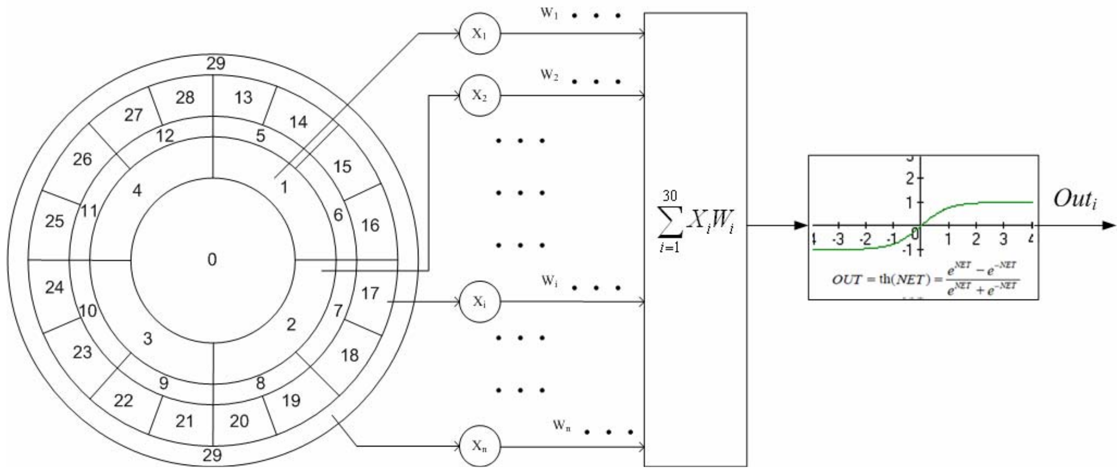


Fig. 9. Structural functional diagram of neural networking recognition of spotted images

For optimization of NN training the next element will be chosen in accordance with heuristic rule. While each iteration recognition error of each element of the sample changes, that is why, for improvement and acceleration of training process we suggest to select the elements, the error of which is higher as compared with the error of the rest of the elements. Hence, the probability of selection of the given element of training sample equals the ratio of recognition error of the given element to current sum of recognition errors of all elements of the sample.

$$p_i = \frac{E_i}{\sum_{i=1}^{30} E_i} . \tag{7}$$

To obtain more complete information regarding NN image recognition, than belonging to certain class we will introduce the notion of “confidence coefficient” for NN classification. The task of classification of laser route spotted images provides two classes and, correspondingly, two reference outputs of the network take values in the range [-1;1]. Output of the network (1;-1) corresponds to correct image (“good”), and output(-1,1) corresponds to incorrect(“bad”) image. While recognition of the given image certain value is formed at the output, this value does not equal to reference output [5]. We will introduce NN error functional [9] while recognition of the image (frame), the expression of which in general form is the following:

$$E = \frac{1}{4} \sum_{i=1}^{n} (Out_i - Out(k)_i)^2 , \tag{8}$$

where Out_i – is the value of i^{th} reference output of the net after classification; $Out(k)_i$ – is the value of i^{th} reference output of the network that corresponds to recognized class K; n – is the amount of NN outputs (equals the number of classes, in the given case $n = 2$).

The given error is found in the range [0,n-1].

Thus, maximum value of the error E_{max} = n – 1 = n, and corresponds to the output of the network (1;1). Then the coefficient of the confidence of classification is –

$$C = 1 - E/E_{\max} . \tag{9}$$

Testing of IC along the total length of video route of laser beam (2044 of spotted images) in real time showed the following results: 74% – correctly classified (“good”) images and 60% – “bad” images. The results of testing proves serviceability and adequacy of the chosen approach.

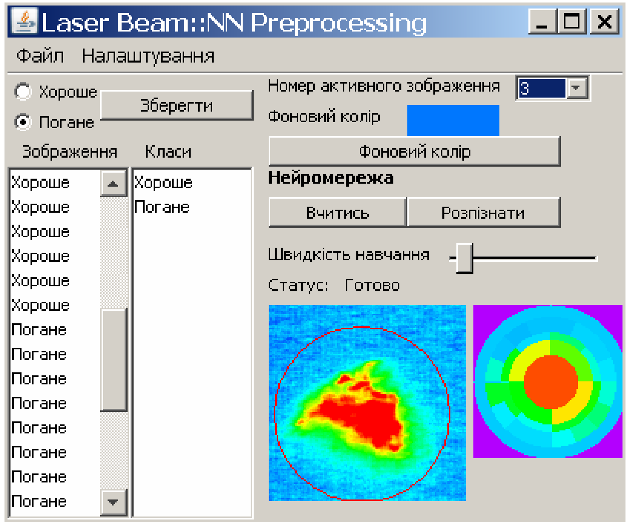


Fig. 10. Screen version of NN program realization

Table 2

The results of neuronetworking recognition of images

Parameter	+	-	All	Parameter	+	-	All
Sample 1	20	20	40	Sample 2	100	100	200
Recognised	19	18	37	Recognised	92	87	179
Percentage	95	90	92,5	Percentage	92	87	89,5

where „+” – is the class of images without important distortions (“good”), „- ” – is the class od distorted images (“bad”), „All” – total number of images.

Conclusions

Methods of preprocessing and neural networking recognition of multicolored spotted images allowing to increase the rate of image processing and optimize structural-functional organization of neural networking system (by the number of layers and internal connections between layers) and computational power are suggested. By the results of computer simulation program emulation of recognition intelligent system is performed (two main blocks are realized:^ preprocessing and compression of the image and the process of neuronetworking recognition) enabling to recognize spotted images of laser beams with higher accuracy. This is a necessary condition for further verification of laser systems.

Application of the suggested model of IC in the tasks of spotted images recognition allows to increase the efficiency of the process of laser beams profiling. The suggested approach in future can be applied in other spheres, for instance, for data recognition on photothermographic geographic maps. The validity of computer simulation and adequacy of the chosen neural networking model are proved by the results of testing of program realization of intelligent system of recognition (96,7% of correctly recognized images of training simulation sample, 90% - validation simulation, sample 92.5% of correctly recognized images, and on real laser route of 2044 frames 77% of “good” images and 60% of “bad” images are recognized correctly).

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