Development of the Anisotropic Filtration Method for Automated Recognition of Authenticity of Banknotes by their Images

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***Abstract* — This article describes the device and control program for automated recognition of authenticity of banknotes. A technique for pre-processing the image of banknotes for improving the quality of recognition is presented. The analysis of the use of anisotropic filtration in recognition of the authenticity of banknotes has been carried out. The results of experimental studies are given.**

***Keywords* — banknote, the authenticity of banknotes, image processing, noises, anisotropic filtration.**

I. INTRODUCTION

The production of banknotes is a complex production process, which includes: the production of special paper; making special paints; the use of complex technologies to create original forms; the use of specific methods and types of printing, which differ from those generally accepted in the printing industry; use of special (visible and hidden) means of protection, etc. All this combined is intended to ensure the protection of banknotes against counterfeiting. However, the current level of development of computer technology, as well as the wide distribution of color copiers, caused favorable conditions for the production of counterfeit banknotes.

Automating the authentication process of banknotes, including the creation of information retrieval systems containing information on the main security features of banknotes from different countries, are characteristic trends in the development of equipment for checking paper money.

The main difficulties encountered in the automated determination of the authenticity of banknotes are related to the variety of fonts used in the production of banknotes, different size of characters, their writing style, non-straightness of arrangement in the line, as well as image defects caused by prolonged use of the banknote.

In the study of the existing principles for the construction of automated recognition of banknotes, as disadvantages can be noted: the absence of the possibility of combining with the automated control system of banking institution; hard programming to recognize a specific type of banknote; absence of learning opportunities. Therefore, the tasks of automating the process of determining the authenticity of banknotes and developing an effective model of a banknote image recognition system are relevant.

II. DEVELOPMENT OF THE STRUCTURAL SCHEME OF THE AUTOMATED RECOGNITION DEVICE OF THE BANK NOTES AUTHENTICITY AND RECOGNITION PROGRAMS

In Fig. 1 shows a block diagram of an automated recognition system for the authenticity of bank notes.

Fig. 1. Block diagram of the automated recognition of banknote authenticity

In Fig. 2 shows the block diagram of the recognition program.

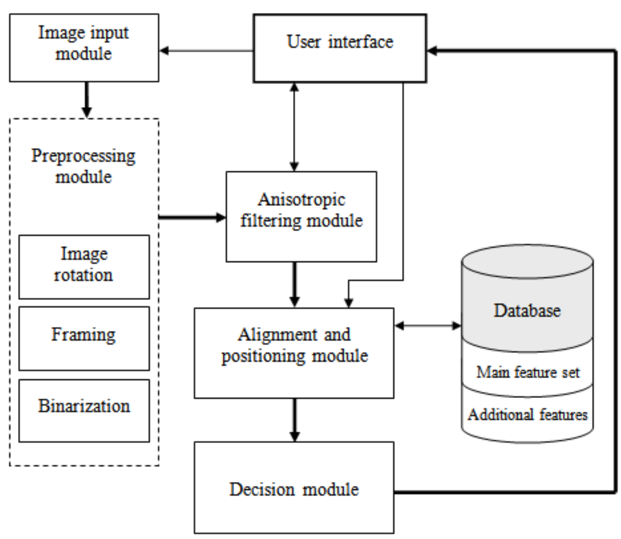

Fig. 2. Block diagram of recognition program

The recognition program consists of the following components.

Image input module, controls the operation of the WEB-camera with the help of the corresponding subroutine-driver. Pre-processing module converts the resulting image.

The image obtained using the camera may have a slight inclination relative to the horizontal axis caused by the absence of caliber devices in the input device design.

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An example of an image having a inclination is shown in Fig. 3. The following algorithm is used to find the angle of rotation.

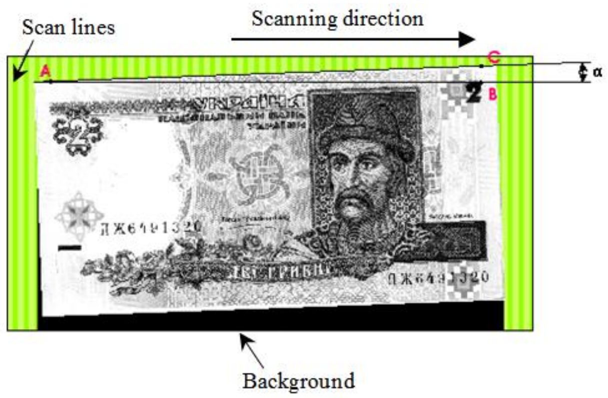


Fig. 3. Sample image having an inclination

Starting from the top left corner, from left to right and top to bottom, an image is scanned. Since a black background was used when scanning the image, it is easy to determine the banknote border.

Having determined the upper limit of the banknote, we will construct a triangle by points ABC (see Fig. 3), departing from the left and right border of the banknote by 20 pixels. This is due to the fact that the scanning may blur the corners of the image, as well as banknote defects (see. Fig. 4).

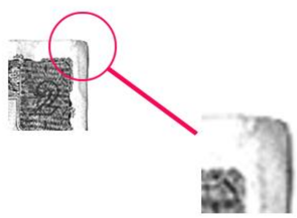


Fig. 4. Blur of image corners

Using the theorem of cosines and sinus theorem we find the image inclination angle.

After determining the angle of inclination of the banknote image, the image is rotated using the “image rotate” module.

Further, on the basis of the data on the size of the banknote, framing is executed, i.e. unnecessary details are cut around the image.

After the rotation, and framing the image of the banknote enters the binarization module.

In the process of binarization, each pixel of the halftone image according to any rule must be set to 0 or 1.

The main difference between the resulting image and the usual binary is that in this case the rule for converting a pixel to a binary value is a function of a non-similar grayscale image.

The binarization threshold is not set rigidly before the program starts, but is selected adaptively on the basis of the analysis of the current grayscale image. Systems with an adaptive binarization threshold occupy an intermediate position between pure binary and halftone.

Most of the methods for adaptive threshold selection are based on the analysis of the brightness of the halftone histogram.

Brightness histogram is a graph n(t), where t is brightness level, and n(t) is the number of pixels of the image that have this brightness value. Usually the histogram is depicted as a series of columns of the same width.

An example of a histogram of an image with 256 levels of brightness is shown in Fig. 5.

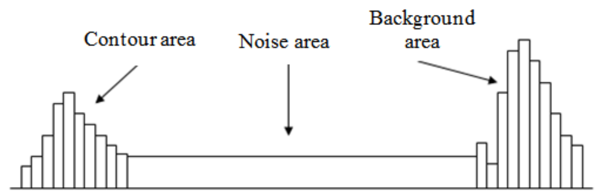


Fig. 5. Sample of image histogram

The task of choosing the threshold is solved especially simply if the brightness levels of the original image have a binary distribution, i.e. the brightness histogram has two pronounced peaks and one trough. Binary distribution means that the image is dominated by two levels of brightness, one of which usually corresponds to the background and the other to the object. For the most accurate separation of the background and the object, the threshold should be chosen equal to the value of the trough.

A histogram of the brightness of a real image usually has many small and high peaks and trough.

An effective method to search for significant peaks and trough is to determine local maximum and minimum in a floating window wide ± K. The value of K is advisable to choose equal to half the expected distance between adjacent significant peaks.

The alignment and positioning module shows the degree of fragments matching of the study image with sets of etalons stored in the database.

The work of this module is based on the use of the correlation recognition method.

The correlation degree is determined by the formula:

$$K(x,y)=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\delta}{L}$$

where L is number of pixels equal to 1;

$$\delta=\begin{cases}1, \text{ if } a_i(\hat{x},\hat{y})=a_i(\breve{x},\breve{y}) \text{ and } a_i(\breve{x},\breve{y})=1,\\ 0, \text{ if } a_i(\hat{x},\hat{y})\neq a_i(\breve{x},\breve{y}).\end{cases}$$

The database contains a set of basic features that are directly involved in the recognition and a set of additional features, the need for which arises only in the case of an uncertain situation.

In the module of decision making the conclusion about the belonging of the image to a particular class is made. The conclusion is made on the basis of the obtained information about the alignment degree of all the image characteristic segments with the etalons, and also taking into account the weighting factors of each of the segments.

III. PROCESSING OF THE BANKNOTE IMAGE BY THE ANISOTROPIC FILTRATION METHOD

With automated recognition of banknote authenticity, we are confronted with the presence of various noises in the image. The occurrence of noise is due to the influence of the image input device and the wear of the banknote. It is known that during the exploitation of the banknote wears out, there are worn out, bends, and areas of contaminated image. Therefore, a problem in spatial image filtration arises.

Anisotropic filtration is most widely used for spatial image filtration. Discrete interpretation of the latter leads to the relation:

$$\widetilde{a}_{ij} = \Lambda\left[\sum_{\nu=-N_a/2}^{N_a/2}\sum_{\xi=-N_a/2}^{N_a/2} a_{i+\nu,j+\xi}\,\omega_{\nu\xi} - \eta\right],$$

where $\widetilde{a}_{ij}$ is matrix element of the filtered image located at the intersection of the i-th line and j-th column; $a_{i+\nu,j+\xi}$ is the image matrix element, distorted noises, located at the intersection of the $(i+\nu)$-th line and $(j+\xi)$-th column; $\omega_{\nu\xi}$ is the aperture element, which is a matrix of size $N_a \times N_a$ (N_a is usually an odd number), located at the intersection of the ν-th line and ξ-th column; η is filter threshold, constant; Λ is threshold function equal to

$$\Lambda(x) = \begin{cases} 0, \text{ if } x < 0; \\ 1, \text{ if } x \geq 0. \end{cases}$$

In Fig. 6 shows examples of images distorted by noise. Filtration quality is determined by the coefficient:

$$\rho = \frac{M_n}{M_f},$$

where M_n is the number of elements in the frame distorted by noise that do not coincide with the corresponding elements of the etalon (original) image; M_f is the number of elements of the filtered image that does not coincide with the corresponding elements of the etalon.

A set of weights aperture is commonly used W_i (i = 1, 2, …, 6), each of which is answered by three different values of these weights ω_j (j = 1, 2, 3), given in the Table 1.

The results of a single filtration are shown in Fig. 7.

Sections corresponding to the said sets of distributions are shown in Fig. 8.

In Fig. 9-11 shows the graphs of the experimental results of a single filtration of the image of objects 1 - 3, respectively.

Etalons

P_n = 5%

P_n = 10%

P_n = 20%

P_n = 30%

P_n = 40%

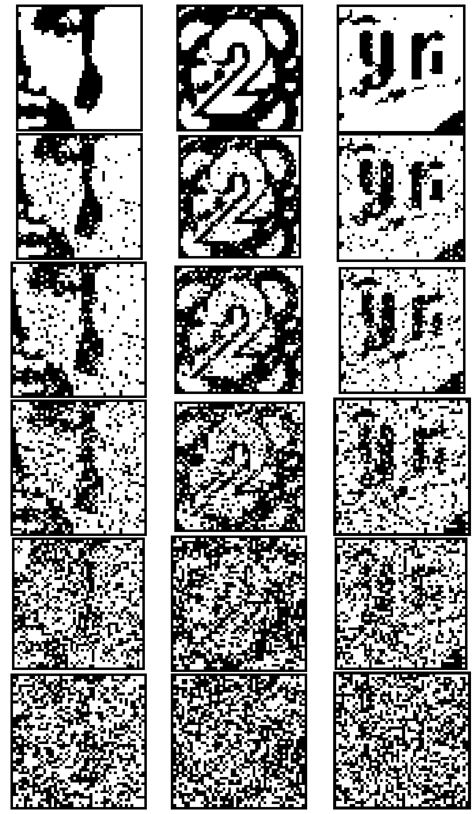


Fig. 6. Image is distorted noise (P_n is noise level)

TABLE I
SET OF WEIGHTS W_i (i = 1,2, …, 6)

W_i	σ_a	ω_j		
		ω_1	ω_2	ω_3
W_1	0,50	0,440	0,070	0,000
W_2	0,70	0,270	0,080	0,005
W_3	1,00	0,150	0,060	0,020
W_4	1,25	0,100	0,060	0,020
W_5	2,00	0,060	0,045	0,030
W_6	2,50	0,060	0,060	0,025

P_n = 10%

W_2

W_4

W_6

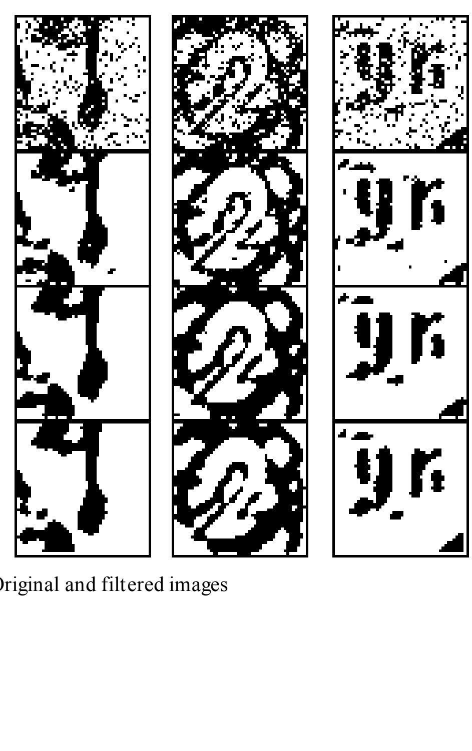


Fig. 7. Original and filtered images

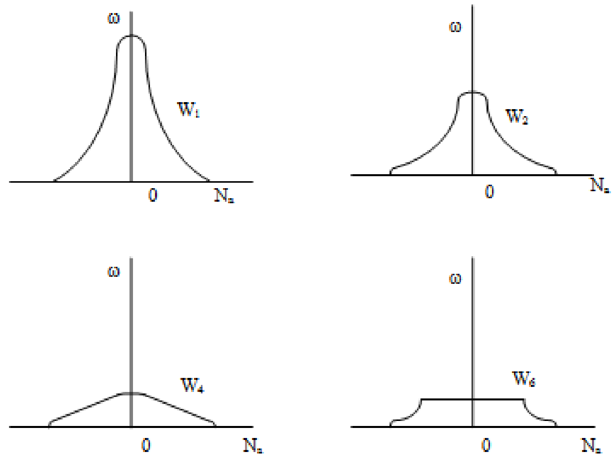
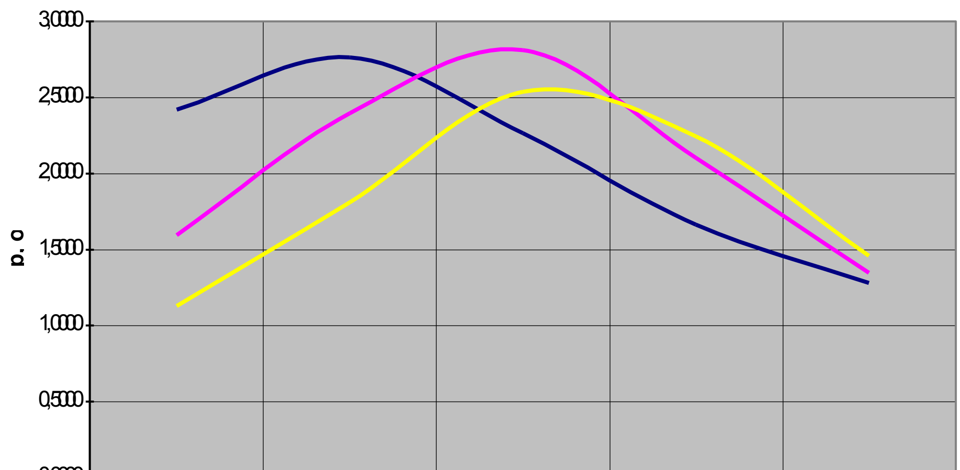
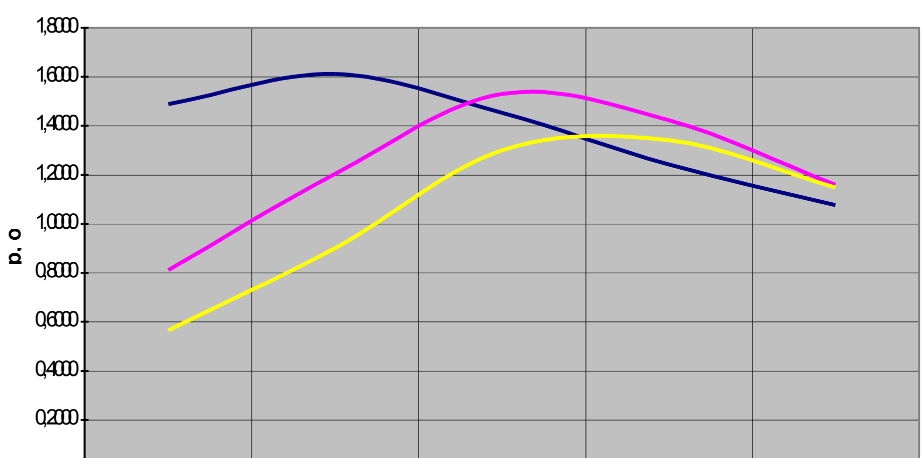


Fig. 8. Sections of normal distributions corresponding to the sets of weights W_i (i = 1, 2, …, 6) given in the Table. 1



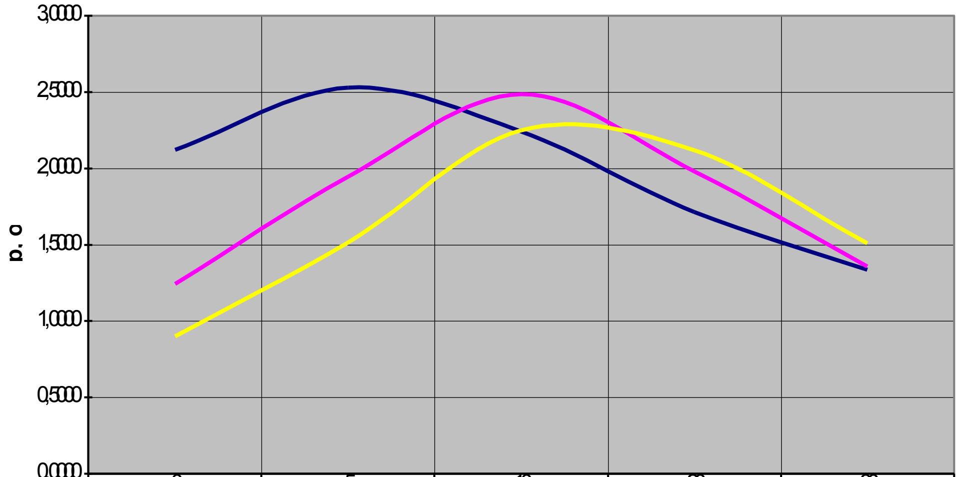
Pn,%	0	5	10	20	30
W2	2,4185	2,7623	2,2652	1,6635	1,2817
W4	1,5934	2,3964	2,8116	2,1040	1,3479
W6	1,1277	1,8104	2,5379	2,2435	1,4597

Fig. 9. Graphs of experimental results of a single filtration of an image of an object 1



Pn,%	0	5	10	20	30
W2	1,4891	1,6110	1,4532	1,2425	1,0766
W4	0,8109	1,2088	1,5303	1,4238	1,1590
W6	0,5654	0,9013	1,2999	1,3410	1,1479

Fig. 10. Graphs of experimental results of a single filtration of an image of an object 2



	0	5	10	20	30
W2	2,1225	2,5279	2,2406	1,7140	1,3365
W4	1,2427	1,9466	2,4864	1,9800	1,3577
W6	0,8988	1,5145	2,2484	2,1186	1,5081

Pn,%

Fig. 11. Graphs of experimental results of a single filtration of an image of an object 3

Any dependence of the filtration quality factor $\rho = f(p_n)$ on these figures is based on the results of processing 50 variants of applying noise on the corresponding image of objects 1, 2 or 3 for the value of p_n for which it was evaluated.

In all cases, it was assumed that η = 0,016. As can be seen from the graphs showed in Fig. 9 - 11, with $p_n \approx 10\%$ for filtration it is advisable to use a set of elements with weights W_2, a при $p_n \approx 25\%$ is a set of elements with weights W_4 or a set of elements with weights W_6.

The results obtained, as expected, indicate that the images with narrow protruding parts are smoothed the worst.

IV. Conclusions

By analyzing the pattern recognition methods based on the identification of point images, it was found that to increase the efficiency of automated banknotes authenticity determination must use the correlation detection method.

Based on the analysis of existing models of image recognition, a model has been developed that is adapted to determine the authenticity of banknotes. This model allows to increase the accuracy of automated recognition of banknote authenticity.

It is shown that using an anisotropic filtration method due to the adaptive selection of the type of aperture depending on the state of the banknotes under consideration, it is possible to solve the problem of extracting characteristic image elements from the background noise.

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