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OBJECTS (SIGNALS) IDENTIFICATION USING ESTIMATED INFORMATION ENTROPY OF TWO-DIMENSIONAL MONOCHROME IMAGES

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ІДЕНТИФІКАЦІЯ ОБ’ЄКТІВ (СИГНАЛІВ) ЗА ОЦІНКАМИ ІНФОРМАЦІЙНОЇ ЕНТРОПІЇ ЇХ ДВОМІРНИХ МОНОХРОМНИХ ЗОБРАЖЕНЬ

Purpose. Improving the efficiency of the objects identification computational methods using their monochrome images through the development of efficient technologies, methods and means of processing of digital representations (signals) with variable and changing information entropy. Development of the object identification method based on processing of probabilistic representations and projections that are formed using statistical evaluation of information entropy values of related fragments of objects characteristics. Investigation of the efficiency of correlation based processing of signal entropy representations and projections that are implemented based on the proposed approach.

Methodology. The main scientific results and conclusions were made on a basis of information theory, theory of signals and systems, probability theory and mathematical statistics, methods of spectral and statistical analysis, digital signal processing and based on results of computational modeling.

Findings. Based on computational modeling it was discovered that the proposed computational method allows achieving of unambiguous identification under information loss caused by image distortion that does not exceed 87%. Besides, the independence of the proposed approach from inverse representation in the case of monochrome images was confirmed.

Originality. The improved computational projection method of the object identification for which construction of projections is proposed to be done by statistical evaluation of information entropy values of corresponding fragments of 2D binary matrices of objects monochrome representations.

Practical value. The proposed method allows increasing the correctness of identification in comparison with known projection based computational methods.

Keywords: *identification, recognition, monochrome images, information entropy estimation*

Relevance of the topic. Modern technologies of image processing and object recognition are widely used in automatic, automated and information-measured systems, monitoring systems, in X-ray and magnetic resonance imaging and so on, for post processing as well as dynamic processing.

In particular, the current tasks include the implementation of markings and labels on containers, trolleys and wagons automatic recognition systems as well as analysis of symbolic information to control and keep records of packed materials (ore, sand, etc.) and energy sources (oil, coal, etc.), fig. 1.

It is appropriate to note that the symbolic information that can be printed in both white and black, undergoes distortion by external factors, including buildup of dirt, change direction and intensity of lighting and so on.

In addition, the fact of the movement (motion) of object-controlled surfaces in conjunction with the factors mentioned above complicates the identification tasks in the systems of industrial usage.

Fig. 1. Representation of character data that is used for identification in the energy sources control and measuring systems

Implementation of modern systems of control and accounting is traditionally based on the usage of video cameras that are attached to the video server, the typical implementation are viewed in [1, 2]. The suitable software actually provides functions of counting and recognition of numbers followed by entering the relevant information in the database.

Operating practices [2] shows that the probability of adequate recognition of characters in such systems does not exceed 75% and only under favorable conditions can reach 95%.

Thus, improving of analytical, information and algorithmic support, software and hardware of automatic and automated control and accounting systems of packed materials and energy sources is an important task. Intensive development, growth of computing power and miniaturization of hardware allows to implementation the distributed control systems with local components of streamlined analysis based on the use of both traditional as well as alternative information sources.

The problem statement. To implement systems for identification objects by their images systems many methods and algorithms have been developed, in particular, based on analysis and synthesis of closed curves in a plane.

In this approach curve is given parametrically as a function of arc length or as the accumulated from the known starting point curvature change. After normalization, this periodic function is expanded in a Fourier series and the coefficients of the truncated transformation are used as the form evidence. The higher order coefficients are describing changes in the direction of the curve for a small length path fragment and their ignorance is equivalent to low frequency filtering. In this case the path noise level is being reduced and the Fourier coefficients that remain keep in a macroscopic shape information [3, 4].

The main disadvantage of the methods of this class is the necessity of performing a large number of calculations when implementing Fourier decomposition algorithms that significantly complicates the algorithmic and software implementations. Recent studies of fractal structures allowed us to use their respective deterministic or probabilistic features [5]. During the processing of the image, which, in addition to the objects, has a background noise, descriptor vectors are grouped around the objects signatures leaving blank space poorly filled in. The cluster dimensions in the descriptor space are defined by given measure signs similarity within a cluster.

The similarity attributes measure variations change cluster dimension and the number of objects that can be attributed to the given class during the recognition. Such approach allows for select an object by fractal elements contours while processing the image [3, 5].

A significant drawback of this approach is the need to cluster images, whereby improperly chosen fragment size leads to dimension estimate distortion because in addition to fractal image the background with different dimensions is included to the analysis area. Besides, it is necessary to form an array of reference images that leads to additional memory consumption and requires significant computational resources. Do not lose their relevance computational methods, in particular correlation based and those, that implies image processing by its projections [3, 4].

In fact, during the projections building the image is mapped to the signal formed by sums of brightness value of pixels located along certain directions. When creating alphanumeric characters projections, which have strokes with a small amount of orientation directions: vertical, horizontal and two diagonal, that coincide with the stroke direction, it appears in the projection as a peak, which can be easily detected with a number of functions, including correlation functions.

Thus, virtually any technique for data processing of digital images its amplitude characteristics, which do not provide full information about the object and decrease analysis efficiency, in particular, in cases of image distortion, and, consequently lead to searching for new or improving of existing processing technologies.

The main part. The result of the research carried out the development of a new method of objects (signals) identification using one or several probabilistic characteristics when processing their 2-dimensional digital representations. As such characteristic entropy, probability distribution of states, variance, standard deviation and central moments of different orders were used. That is when constructing the projection the image is mapped to a vector whose values are a calculation result of one or several probabilistic characteristics of digital representation fragments located along certain directions [6, 7].

The set of all the monochrome images of the size $n \times m$ pixels is in bijective accordance with the set of all the binary matrices of the order $n \times m$, that is it is a vector space of $n \times m$ dimension of a finite field. Denote mapping of the $\{0.1\}^n$ (the space of the ordered sets built from "0" and "1" and having the length n) to the interval $[0.1]$ (of ratings of the information entropy of those sets), that is, the mapping

$$\hat{h}_n : \{0.1\}^n \to [0.1],$$

where

$$\hat{h}_n(i_1, i_2, ..., i_n) = P^{"0"} \cdot \log_2 P^{"0"} + P^{"1"} \cdot \log_2 P^{"1"},$$

where

$$i_j \in \{0.1\}; \quad P^{"1"} = \frac{1}{n}\sum_{j=1}^{n} i_j; \quad P^{"0"} = 1 - P^{"1"}.$$

Let the binary matrix $X \in \{0,1\}^{n \times m}$ be a representation of some object. Denote now the mapping of entropy rates $\hat{h}_h : \{0.1\}^{n \times m} \to [0.1]$ and $\hat{h}_v : \{0.1\}^{n \times m} \to [0.1]$ as follows

$$\hat{h}_h(X) = (\hat{h}_m(x_{11}, x_{12}, \ldots, x_{1m}), \hat{h}_m(x_{21}, x_{22}, \ldots, x_{2m}), \ldots, \hat{h}_m(x_{n1}, x_{n2}, \ldots, x_{nm})) \quad (1)$$

X or a matrix obtained from X by independent permutations of the elements in its columns.

$$\hat{h}_v(X) = (\hat{h}_n(x_{11}, x_{21}, ..., x_{n1}), \hat{h}_n(x_{12}, x_{22}, ..., x_{n2}), ..., \hat{h}_n(x_{1m}, x_{2m}, ..., x_{nm})) \quad (2)$$

where x_{ij} – the element of the matrix X or a matrix obtained from X by independent permutations of the elements in its rows.

The indices h and v in the designation $\hat{h}$ of the mapping actually show that $\hat{h}_h$ – applies to row sand $\hat{h}_v$ – applies to columns of the matrix X.

Thus, each binary image of the object (fig. 2) is associated with a set of projections – vectors of entropy values, which are obtained through applying of the mappings $\hat{h}_h$ and $\hat{h}_v$ to the matrix X and its defined permutations

$$X \mapsto \{\hat{h}_1^{ob}, \hat{h}_2^{ob}, ..., \hat{h}_g^{ob}\} = H^{ob},$$

where the index g means the amount of corresponding projections.

Based on those projections the reference representations for the given amount k of objects $H^e : \{H^{e1}, H^{e2}, ..., H^{ek}\}$ are formed and used then to calculate the coefficients of the correlation with the object being identified. It is appropriate to note that it is necessary to meet the condition $|H^{ob}| = |H^{ei}|$ for $i = \overline{1,k}$. Let $\hat{h}^{ob} \in H^{ob}$ and $\hat{h}^e \in H^{ei}$ be the respective vectors of information entropy values of the object and one of the reference.

In such a case

$$R_{xy}(\hat{h}^e, \hat{h}^{ob}) = \frac{1}{q}\sum_{j=1}^{q} \overset{\circ}{\hat{h}}{}^e[j] \cdot \overset{\circ}{\hat{h}}{}^{ob}[j],$$

where q – the dimension of the vectors $\hat{h}^e$ and $\hat{h}^{ob}$, $\overset{\circ}{\hat{h}}{}^e$ and $\overset{\circ}{\hat{h}}{}^{ob}$ – are the centered vectors of the vectors $\hat{h}^e$ and $\hat{h}^{ob}$ respectively.

This results in a matrix of the correlation coefficients of the involved projections of the object H^{ob} and the references H^e

$$\begin{vmatrix} R_{xy}(\hat{h}_1^{e1}, \hat{h}_1^{ob}) & R_{xy}(\hat{h}_2^{e1}, \hat{h}_2^{ob}) & \cdots & R_{xy}(\hat{h}_g^{e1}, \hat{h}_g^{ob}) \\ R_{xy}(\hat{h}_1^{e2}, \hat{h}_1^{ob}) & R_{xy}(\hat{h}_2^{e2}, \hat{h}_2^{ob}) & \cdots & R_{xy}(\hat{h}_g^{e2}, \hat{h}_g^{ob}) \\ \vdots & \vdots & \ddots & \vdots \\ R_{xy}(\hat{h}_1^{ek}, \hat{h}_1^{ob}) & R_{xy}(\hat{h}_2^{ek}, \hat{h}_2^{ob}) & \cdots & R_{xy}(\hat{h}_g^{ek}, \hat{h}_g^{ob}) \end{vmatrix}. \quad (3)$$

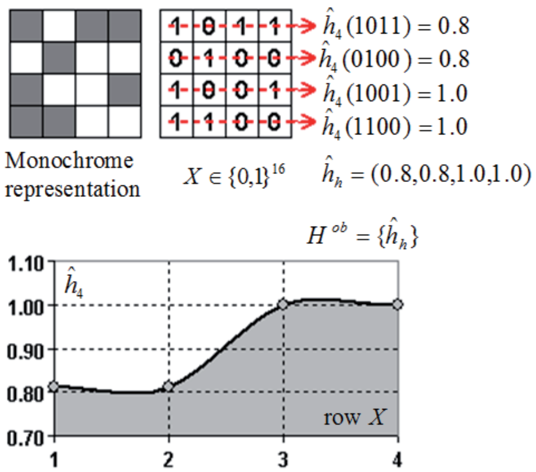

Fig. 2. The scheme of forming the graphical representation of the vertical projection $\hat{h}_h$ of the binary matrix X of the object monochrome image

The compliance of the object with the one of the references is determined by the highest number of the maximum values of the correlation coefficients $R_{xy}(\hat{h}^e, \hat{h}^{ob})$ in one row. If the matrix contains rows with equal numbers of the maximal $R_{xy}(\hat{h}^e, \hat{h}^{ob})$ then the object is not matched, that is the information obtained from the object H^{ob} projections is not enough to identify it. The block diagram of the implementation of the described method is shown on fig. 3.

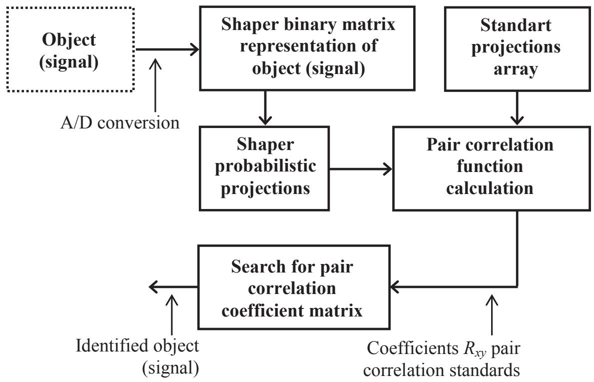

Fig. 3. The block diagram of the object (signal) identifycation using its probabilistic projections

The proposed approach to build projections using information entropy values, calculated according to Shennon's formula is invariant to an inverted object representation.

On fig. 2 we can see that $\hat{h}_4(1011) = \hat{h}_4(0100)$. This is explained by the fact that the occurrence likelihoods $P^{"0"}$ and $P^{"1"}$ of binary symbols in the case of inverse representation are just swapping, and their sum remains the same.

On the next stage the research of the pair correlation coefficients conducted on the base of a series of the fixed graphical images of the digits {0, 1, …, 9}, represented by the corresponding projections $H^e : \{H^{e1}, H^{e2}, ..., H^{e9}\}$, calculated in accordance with their binary matrices.

The results are presented on the fig. 4, (here the references are in the same time the objects being identified) [7, 8].

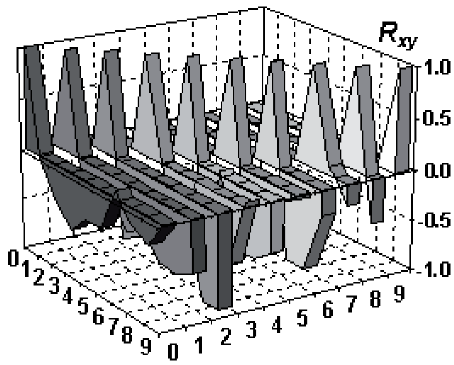

Fig. 4. The pair correlation coefficients of the reference projections $H^e : \{H^{e1}, H^{e2}, ..., H^{e9}\}$ for the test image digits {0.1,…,9}

It was discovered that usage of horizontal and vertical projections (derived from X after appropriate permutations) makes the pair correlation coefficients of

$\{H^{e1}, H^{e2},..., H^{e9}\}$ not to exceed 0.08 for 95.5% cases and 0.21 for 4.5% of the correlation maximum, that is about for 28% less than matrix correlation methods give, in particular the integral projection method.

It's worth to note that during preparing of graphical representations of the object different kinds of distortion caused by environmental exposures, hardware and design sensor limitations, converter errors, etc. appear.

To test the effectiveness of the proposed approach simulation modeling in the computational experiment has been conducted [8], in which the uniform distortion of the graphical representations with white (fig. 5, *a*) and black (fig. 5, *b*) pixels has been carried out followed by the evaluation of the probability of the correct identification the character P_{is}, fig. 6.

It was discovered that for the projections built for the integrated characteristics [3, 4] the accepted level of the correct identification is seen when loss of the information in the graphical representations does not exceed 40% when distorted by black and 30% when distorted by white pixels, fig. 6 graphics *1[w], 1[b]*.

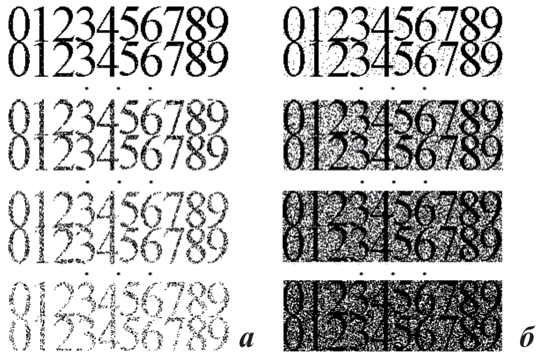

Fig. 5. Fragments of the results of the simulation modeling of the graphical representation distortion with ***a*** *white and* ***b*** *black pixels*

When using other statistical characteristics, in particular, average, variance, square deviation, higher-order central moments, and the correctness of the recognition goes down. The best result among mentioned characteristics is seen for the projections built for variance. It is 20% for black pixels distortion and 12% for white pixels distortion, fig. 6 graphics *2[w], 2[b]*.

In the case of information entropy usage for the reference projections of the first type – implemented by blank (zeros) polygons of the graphical representations the information loss caused by distortion up to 80.2% for white and up to 34.5% for black pixels, has almost no impact on the identification correctness. Besides, for the reference projections of the second type – implemented by filled (ones) polygons the inverse relation is seen for the distortion up to 5.8% caused by white and up to 84.1% caused by black pixels.

The selection of the projection type that will be used for the calculations should be based on the preliminary assessment of the binary matrix infill with ones: if it is below 50% – to use the projections of the first type, otherwise – of the second type.

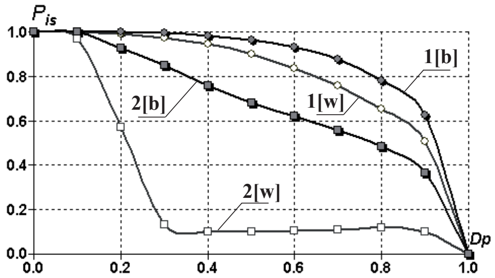

Fig. 6. The change in the probability of the correct identification of the character P_{is} *for the projections built by* ***1*** *the integration and* ***2*** *the variance from the value of the distortion* Dp *by* ***w*** *white and* ***b*** *black pixels*

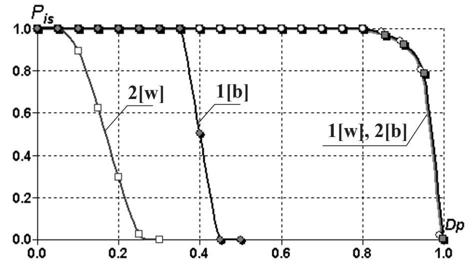

Fig. 7. The change in the probability of the correct identification of the character P_{is} *for the projections of the type* ***1*** *and* ***2*** *for the distortion value* Dp ***w*** *caused by white and* ***b*** *black pixels*

When using the correlation-based approach, in particular, the normalized pair correlation function (4), provides in-element comparison of the graphical representation matrix Y with the corresponding reference representation matrices $\{X^{e1}, X^{e2},..., X^{e9}\}$ the comparable results, shown in the table 1, were received.

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n} \mathring{x}_i \cdot \mathring{y}_i}{\sqrt{D_X \cdot D_Y}}, \quad (4)$$

where n – number of the elements in the matrix; $\mathring{x}_i$ – centered element of the matrix of the corresponding reference $\{X^{e1}, X^{e2},..., X^{e9}\}$; $\mathring{y}_i$ – centered element of the matrix Y of the graphical representation; D_X and D_Y variances of the matrix elements of the reference and graphical representations correspondingly.

The simulation was also made for other correlation this functions that requires less calculations number, including:

- sign

$$S_{xy} = \frac{1}{n}\sum_{i=1}^{n} sign[\mathring{x}_i] \cdot sign[\mathring{y}_i], \quad (5)$$

where

$$sign[x_i] = \begin{cases} 1, & x_i > 0 \\ 0, & x_i = 0 \\ -1, & x_i < 0 \end{cases};$$

- structure

$$C_{xy} = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2 \quad ; \qquad (6)$$

- modular

$$G_{xy} = \frac{1}{n}\sum_{i=1}^{n}|x_i - y_i| \quad , \qquad (7)$$

where x_i – the matrix element of the corresponding reference $\{X^{e1}, X^{e2},..., X^{e9}\}$; y_i – the element of the matrix Y of the graphical representation.

Table 1

Dependency of the Character P_{is} on the Distortion Level Dp for the Correlation Based r_{xy} and the Proposed H Approaches

Dp	P_{is} for r_{xy}	P_{is} for H
0.80	1.0000	1.0000
0.81	1.0000	0.9999
0.82	1.0000	0.9999
0.83	1.0000	0.9985
0.84	1.0000	0.9948
0.85	1.0000	0.9885
0.86	1.0000	0.9784
0.87	1.0000	0.9685
0.88	1.0000	0.9649
0.89	0.9999	0.9567
0.90	0.9999	0.9472
0.91	0.9999	0.9401
0.92	0.9998	0.9356
0.93	0.9997	0.9307
0.94	0.9996	0.9204
0.95	0.9994	0.8558
0.96	0.9971	0.8492
0.97	0.9883	0.8369
0.98	0.9597	0.8247
0.99	0.7796	0.6974

Table 2

Dependency of the Character P_{is} on the Value of Its Distortion Dp for the Correlation Methods Processing S_{xy}, C_{xy} and G_{xy}

Dp	P_{is} for S_{xy}	P_{is} for G_{xy}	P_{is} for G_{xy}
0.0	1.0000	1.0000	1.0000
0.1	1.0000	1.0000	1.0000
0.2	1.0000	1.0000	1.0000
0.3	1.0000	1.0000	1.0000
0.4	1.0000	1.0000	1.0000
0.5	1.0000	1.0000	1.0000
0.6	0.9995	0.9995	0.9985
0.7	0.9002	0.9007	0.7834
0.8	0.5141	0.5159	0.4388
0.9	0.2014	0.2034	0.1002

As we can see, the usage of simplified correlation functions significantly decreases the probability of the correct character identification.

According to the results of the simulation the invariance of the proposed method to the inverse representation has been confirmed [6], fig. 8, in fact the probability of binary symbol appearance in the mapping $\hat{h}_h: \{0.1\}^{n\times m} \to [0.1]$ and $\hat{h}_v: \{0.1\}^{n\times m} \to [0.1]$ after inversion exchange their values, but the entropy value calculated by the corresponding probabilities of the symbol appearances (Shannon formula) remains the same.

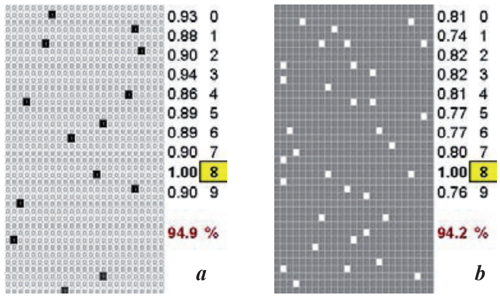

*Fig. 8. Fragments of the identification simulation results for the **a** direct and **b** inverse representation of the digit eight*

It is worth noting, that the correlation function usage requires more memory to store the references in comparison to projection methods. Besides, the centering operation causes matrix element type change to floating point number resulting in higher computational cost in comparison to integer operations required during projections building.

Conclusions. The proposed approach allows increasing the correctness of identification in comparison to the known projection methods and provides the comparable effectiveness in comparison to the correlation methods using probabilistic, in the shown case entropy based, representation when building projections. In addition, the probabilistic characteristics usage allows significantly reducing and in some cases eliminating the impact of single distortions.

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Мета. Підвищення ефективності обчислювальних методів ідентифікації об'єктів з використанням їх монохромних зображень на основі розвитку ефективних технологій, методів та засобів опрацювання цифрових представлень (сигналів) з варіативною та змінною інформаційною ентропією. Розроблення методу ідентифікації об'єктів на основі опрацювання ймовірнісних представлень та проекцій, що формуються шляхом статистичного оцінювання значень інформаційної ентропії відповідних фрагментів їх характеристик. Дослідження ефективності кореляційного опрацювання ентропійних представлень сигналів та проекцій, що реалізуються на основі запропонованого підходу.

Методика. Основні наукові результати та висновки зроблені на основі використання теорії інформації, теорії сигналів і систем, теорії ймовірностей та математичної статистики, методів спектрального та статистичного аналізу, цифрового опрацювання сигналів, а також за результатами моделювання в обчислювальному експерименті.

Результати. Встановлено, що запропонований обчислювальний метод дозволяє забезпечити однозначну ідентифікацію при інформаційних втратах, зумовлених спотворенням зображень, що не перевищують 87%. Підтверджена інваріантність запропонованого підходу до інверсного представлення для випадку монохромних зображень.

Наукова новизна. Удосконалений обчислювальний проекційний метод ідентифікації об'єктів, за яким побудову проекцій запропоновано здійснювати шляхом статистичного оцінювання значень інформаційної ентропії відповідних фрагментів двомірних бінарних матриць їх монохромних представлень.

Практична значимість. Полягає в тому, що запропонований метод дозволяє збільшити адекватність ідентифікації порівняно з відомими проекційними обчислювальними методами.

Ключові слова: *ідентифікація, розпізнавання, монохромні зображення, оцінка інформаційної ентропії*

Цель. Повышение эффективности вычислительных методов идентификации объектов с использованием их монохромных изображений на основе развития эффективных технологий, методов и средств обработки цифровых представлений (сигналов) с вариативной и переменной информационной энтропией. Разработка метода идентификации объектов на основе обработки вероятностных представлений и проекций, которые формируются путем статистического оценивания значений информационной энтропии соответствующих фрагментов их характеристик. Исследование эффективности корреляционной обработки энтропийных представлений сигналов и проекций, реализуемых на основе предложенного подхода.

Методика. Основные научные результаты и выводы сделаны на основе использования теории информации, теории сигналов и систем, теории вероятностей и математической статистики, методов спектрального и статистического анализа, цифровой обработки сигналов, а также по результатам моделирования в вычислительном эксперименте.

Результат. Установлено, что предложенный вычислительный метод позволяет обеспечить однозначную идентификацию при информационных потерях, обусловленных искажением изображений, которые не превышают 87%. Подтверждена инвариантность предложенного подхода к инверсному представлению данных для случая монохромных изображений.

Научная новизна. Усовершенствован вычислительный проекционный метод идентификации объектов, по которому построение проекций предложено осуществлять путем статистического оценивания значений информационной энтропии соответствующих фрагментов двумерных бинарных матриц их монохромных представлений.

Практическая значимость. Заключается в том, что предложенный метод позволяет увеличить адекватность идентификации по сравнению с известными проекционными методами, а также получить соизмеримые результаты по сравнению с корреляционными матричными вычислительными методами.

Ключевые слова: *идентификация, распознавание, монохромные изображения, оценка информационной энтропии*

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