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# ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

# INCREASING THE ACCURACY OF TECHNICAL VISUAL INFORMATION-MEASUREMENT SYSTEMS OF MOBILE ROBOTS

Specialty: **3337.01-Information-measuring and control systems (Technique)**

Field of science: **Technical sciences**

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The work was performed at Azerbaijan State Oil and Industry University, "Electronics and automation" department.

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## GENERAL CHARACTER OF THE WORK

**The topicality of the subject.** Mobile roboto-technical systems are used today in various fields. Corporate customers are interested in multifunctional industrial robots, mass purchasers get intellectual vacuum cleaners and robotic dogs, and security services and defenders rely on autonomous devices having the ability to solve problems connected with following and searching.

In this case, all such devices should ideally move in a strange and unexpected state of the real world steadfastly.

A generalized structural-functional scheme of a robot interacting with the environment is illustrated in Figure 1. The robot generally consists of 4 systems: communication systems with information-measurement ("Sensory"), control ("Brain"), executor ("Motor"), and other robots, human or robot internal systems ("Language").

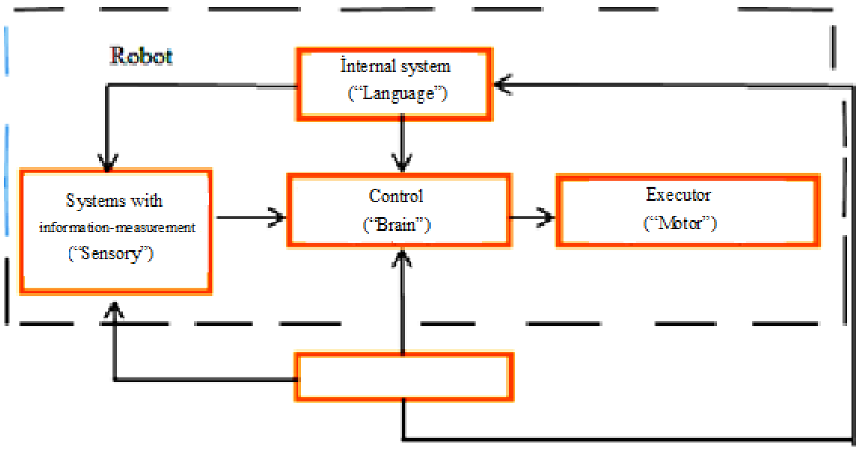


**Figure 1. Generalized structural-functional scheme of a robot interacting with the environment**

Information-measurement system ("Sensor") is a robot artificial sensing body designed to receive and transform information about the robot's state, according to users of the external environment and robot control system ("brain").

The robot control system is designed for the followings: First, for the development of the law for controlling the mechanisms (engines) of the executive system using the feedback signals of the information-measurement system; second, for the communication of human and robot in any language. The robot's intellectual capabilities are defined by the information-measuring and control system.

The robot's executive system serves to execute control signals formed by the control system, as well as affecting the environment. Samples of executive systems: manipulators (mechanical hands), pedipulators (mechanical feet), self-propelled carts, 3D-tomography apparatus, etc.

The robot communication system is designed to organize information exchange between robot systems, robots and human or other robots in a language they understand. The purpose of this exchange is to provide a brief summary of the tasks assigned to the robot, the organization of a dialogue between human and robot, the control of the robot's activity, diagnostics of malfunctions, and routine inspection of the robot.

According to the functional scheme, one of the main places in the structure of the adaptive robot is occupied by the IMS.

A generalized structural scheme of modern information-measurement control systems (MIMCS) [16] with mobile robots (MRs) is presented (Figure 2), where: ID - initial data; EE - external environment; AMCS - autonomous movement control system; CDB - cartographic database; EEMFS-External environment model formation system; MPS - movement planning system; ES and NS - executive and navigation systems; TCs – tracking conductors.

As it is seen from Figure 2, technical vision systems (TVS) is more widespread in comparison with other sensor systems, and therefore has the greatest semantic potential for recognition of external objects during cartography, as well as the ability to perform external motion.

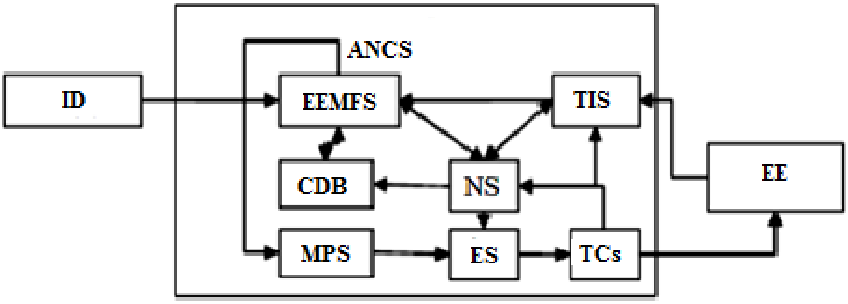


**Figure 2. Generalized structural scheme of modern information-measuring control systems of mobile robots (MR)**

The work of TVİMS primarily deals with the processing and analysis of visual information, that is, images of the working area.

Despite the specific cases of application of the recognizable object image with high reliability, it has the general basic structure in Figure 3, where 1 is measuring channel: 8 is illumination device, 9 is the initial object, 10 is input object image parameters array for image recognition, 11 is analog-discrete and 12 is discrete digital converter and 13 is transformer, 2 is memory device designed to store the digital equivalent of the standard object, 3 is the block of MVO, specifying the 4 - devices that record their inclination of the unit given in block 5, 6 is the block forming the signaling system of devices, inclination and adjustment effects. The work of the system is managed by the controller device- 7.

The literature sufficiently deals with the processing of visual information with the help of computers. However, the features of robotic-technical issues that require large-scale data processing in real-time computational and affordable microprocessor compounding complicates the use of digital methods and analysis of image processing.

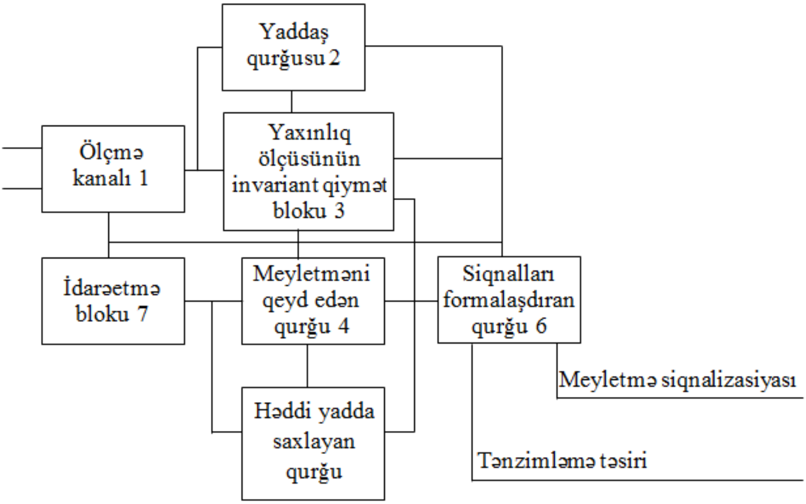


**Figure 3. Proposed generalized structural scheme of technical visual systems with increased accuracy of recognition by the correction of error measurement of image parameters**

In most production issues, the function of the IMS includes such operations as execution of the object type, defining its condition and direction. When the object is within a specified distance from the video viewer of technical vision system, these operations are successfully performed, i.e. image analysis is performed on a fixed scale. Currently, it is enough to have a set of invariant signs of moving and turning around in the technical vision system's recognition system. The problem of defining the type, condition and direction of an object on an ever-changing scale is still unresolved.

The reduction of videoinformation volume in IMS is mainly carried out by half-tone binarization of the images, i.e. the representation of the image in two gradient (color or half-tone) images. Binary image analysis is simpler than half-tone image analysis and is performed fairly quickly. In addition, it is easier to define the features of the object (topology, meters, etc.) in a binary image. For this reason, the vast majority of TVIMS processes and analyzes binary images of objects [11].

Binarization can be performed in two ways:

1. General binarization of a contrast object and background is carried out sufficiently in the image. All colored pixels are accepted as the pixels of an object. In this case, colored pixels are assigned by single values, and background pixels are assigned by zero values.

2. In poor contrast, depending on the color model, the image is divided into layers by the degree (R, G, B) or brightness (Y). As a result, several monochrome images are captured. Color pixels are then assigned by single values, and the remaining pixels are considered as background pixels with zero values [15,23].

For initial algorithms of multi-stage image processing, binary images are used as input data, which provides the most favorable results in sufficient contrast of objects and background images. Therefore, the analysis of binary images in this work is given a great deal of attention. The binary image has a black and white dot. In this case, the black pixels in the image correspond to the points of the object and the background dots correspond to the white pixels of the image. Based on this, the binary image can be represented in the form of data array of “1” and “0”, in this case the object is assigned by “1” and the background by “0”.

In the release of small and medium series, the use of rigidly programmed robots is connected with a big challenge. Therefore, much attention is paid to the creation and application of adaptive robots capable of correcting their performance according to the working area conditions, based on real-time sensor information in industrial settings. One of the key positions in the structure of the adaptive robot is the IMS. This is primarily connected with the analysis and processing of visual information, that is, the images of the working area.

Currently, there is a demand for intellectual systems of information processing in many areas of science and technology [9,35,36,48,85,100]. Human is taken as a model of such systems. As it is known, human receives most of all the information by sight, and the whole human activity is focused on visual processing of information. Therefore, TVS is a key element of the intellectual information processing system, and TVS efficiency is a key factor in the development of the entire intellectual system.

It is well-known that effectiveness is a generalized parameter characterizing the quality of TVIMS in solving the stated problems. The effectiveness of TVIMS is mainly characterized by three parameters in its operation: rapid recognition of objects, reliability and accuracy.

The level of rapid working and reliability is directly dependent on the level of technical means development and is currently quite high. As for the recognition accuracy of TVIMS facilities, the problems connected with the high demands for accuracy, as well as the variety and complexity of the issues presented, have not been solved yet, i.e. recognition accuracy of objects is one of the most important parameters determining TVIMS effectiveness.

Getting acquainted with the sources of TVIMS has shown that the recognition accuracy of objects is influenced by the following factors: the presence of noise in images, the spatial transformation of objects (sliding, rotation and scaling), and non-ideality of proximity measurement.

In this regard, the subject of the work dedicated to the development of methods, algorithms and tools to increase the recognition accuracy of objects according to the images is a topical scientific and technical issue.

Generally, the error in recognizing images due to their $\delta$ signs can be presented to the following dependence:

$$\delta = f(\sigma_{\text{noise}}, \sigma_{\text{spatial transfor..}}, \sigma_{\text{MVO}}) \quad (1)$$

where $\sigma_{\text{noise}}$ is the error of computing the number of pixels concerning the object and background, as well as the signs in the object shape changing; $\sigma_{\text{spatial transfor.}}$ is the error of computing signs in change of number and absolute value of signs; $\sigma_{\text{MVO}}$ is the error of computing the signs due to systematic errors and magnitude effects of proximity measurement.

**The purpose of the work**. The aim of the dissertation is to develop an effective method for recognizing objects based on images in increasing the accuracy.

The following problems have been solved to achieve the goal:

1. Noise level analysis was performed depending on the noisiness degree of binary images of fully- connected masks and objects with simple algorithm and logical filtration.

2. Noise level algorithm was developed in binary images of objects.

3. Methods for recognizing object image were developed by determining their mutual location at appropriate scopes according to standard description.

4. Dependence formulas for the moment of inertia of the object's image on the rotation and scaling of the image were obtained.

5. The formulas for the value with invariance and minimal sensitivity of the systematic and random errors in the measured values of object (MVO) and scale parameters was developed.

**Scientific novelty of the work**. The following scientific results were achieved during the research process:

1. Noise level algorithms were proposed in the binary images of objects by selecting image points and measuring geometric parameters.

2. A method for recognizing a single and multi-countered object for a standard image by determining mutual location was proposed according to the scale.

3. A system of formulas showing the dependence of the object's image on the rotation of moment of inertia and the change in scale was proposed.

4. Formulas were proposed for the values of MVO providing additives and multiplicative errors of the recognized object and the standard images and invariance of object recognition to change systematic errors of the measured values of the object and scalability parameters with available conditions of identity.

5. The formula was proposed for the value of MVO providing minimal sensitivity in systematic and random errors changing in the measured values of the object and scale parameters during recognition process.

**Research methods**. The research is based on the use of image recognition theory, material resistance, discrete mathematics, trigonometry, and software in the Matlab environment. In order to approve the theoretical results, computer modeling was performed using the Matlab environment.

**The practical value of the work is resulting in the followings**:

1. The devices leveling binary noises in the object's image have been developed by measuring geometric parameters protected by the patent of the Republic of Azerbaijan (No. F20130005).

2. The software has been developed to solve the problem of noise leveling in binary images using a computer.

3. The software has been developed to solve the problem of recognizing an object image by determining its location relative to any standard condition.

The designed devices and software can be used for recognizing the objects on satellite images.

**Carrying out the results of the work**. The algorithms and software systems presented in this work have been applied to the image processing process by the Information Processing Center of the Special Design Bureau of the National Aerospace Agency. Also, the results of the scientific research were used as laboratory work and lecture materials in the teaching process at Azerbaijan State Oil and Industry University.

**Author's personal presence**. The statement of the problem in the dissertation work, performing an experiment, analysis of the obtained results and generalizations were done by the author himself.

**Publication**. 21 scientific papers on dissertation work, including 1 patent, 10 articles (6 abroad) were published. 10 theses of the reports made at international and national conferences were published.

**Approbation of the work**:. The main provisions and results of the dissertation were reported and discussed: "Information Technologies and Computer Engineering" (Vinnitsa, 2011) BEPK, "Methods and means of coding, protection and compression of information” (Vinnitsa, 2011) BEPK, “Information processes and technologies” (Sevostopol, 2012) in GATBEPK, “Information Technologies in the Modern World. Research of Young Scientists ”(Kharkov, 2013) “Problems of IT Industry and development problems ”(Kharkov, 2015).

**Publications**. The main content of the dissertation has been published in 19 scientific papers, including:

-1 article in the journal “East-European Journal of Technology”, which is included in the list of Scopus;

-1 article in the “International Journal of Engineering Research and Science”, which is included in the Index Copernicus list;

-1 patent of the Republic of Azerbaijan;

-3 articles have been published in the journals included in the list of Higher Attestation Commission of the Republic of Azerbaijan;

-1 article without co-author;

-3 articles have been published in prestigious journals in the Ukraine, Russia and India.

**The volume and structure of the work**: The dissertation consists of an introduction, 3 chapters, conclusion, a list of the literature and an appendix. 203 pages, 33 pages of pictures, 26 pages of tables, 16 page of 144 list of the used literature and 10 pages of appendix are expressed.

**To be defended:**

1. The algorithm for eliminating “1” and “0” noises in the object’s image with one or two pixels by measuring geometric parameters and selecting points of image
2. Graphoanalytic solution of the system of nonlinear equations
3. Computer modeling of noise elimination algorithms in binary images of objects
4. Computer modeling of inter-object proximity measurement that increases the reliability of recognizing the objects by technical visual systems.

## THE PAPER SUBJECT

**The introduction part** grounds the topicality of the work and mentions the need for a technique for recognizing TVS objects that increase the recognition accuracy and presents the purpose, scientific novelty and practical value of the work, and the implementation and approbation of the results.

**The first chapter** presents the application areas of mobile robots, the application of TVIMS in the analysis and processing of binary images of objects, binarization methods, the factors affecting the efficiency of the TVIMS, the methods of noise elimination.

In most cases, images obtained from TVIMS have a "noise" in addition to an image. These may be completely false values of individual pixels that are not related to distortion of the color or brightness of some group pixels or their true color, that is, noises are explained as scattered variation of the isolated elements of the image [36, 49,77].

Due to the distorted nature of the image, the noise can be divided into several types:

• additive noise - some random number with different values at each point is added to the color or brightness value of each pixel;

• multiplicative noise - The color or brightness value of each pixel is multiplied by some random number the values of which are close to the unit and different at each point;

• impulse noise - the color or brightness values of some individual pixels are distorted until they lose any information about the values that are not distorted.

The following methods are used to eliminate noises:

• linear algorithms for each pixel of the image processed by a linear combination of several pixels of the original image;

• elimination algorithms of noises, the values of which are ranked by a rising series and the image is captured based on a sequence list of image pixel brightness;

• local-additive algorithms, the processing structure of which depends on the features of the image, unlike many filters. As a result, unevenness of useful details (boundaries, thin lines, etc.) occurs. Therefore, recent studies relate to the analysis of local-additive filtering algorithms under the influence of different types of noises;

• “expert” algorithms, which simultaneously use several parameters of adaptation and apply an expert system of initial recognition that a point belongs to a given type of object. Then the type of filter is selected according to the made decision;

• algorithms based on pixel grouping for brightness. Image smoothing methods based on pixel grouping, depending on their proximity to the center;

• small-scale noise intensification by differential operators; a combination of differential and superficial operators. The Gaussian and Laplace operators are linear, which is commutative, and can be combined by changing the sequence of operations execution: L*(G*I)=(L*G)*I=LoG*I, where * is the opening. Instead of pre-smoothing the image, opening of both operators is performed, then the obtained operator is applied to the image;

• stochastic gradient operator. An optimal gradient mask defined taking into account the image’s auto-correlation function and signal/noise correlation for a given noise based on it.

Different noise control methods have been developed that provide good results in the known spectral characteristics of noise. However, there are no models of noise processes in practice and there are difficulties in implementing classical techniques in technical visual systems. This is overall dimension-massive indicators in the implementation of a large amount of computational information and the machine. Relatively simple methods based on logical procedures are common [106].

Existing noise elimination algorithms have a general disadvantage - they make the boundaries of the image superficial.

When most elements of the image are exposed to distortion, the effectiveness of noise elimination algorithms becomes more important.

An analysis of existing TVIMS object recognition methods showed that three key factors have negative impact on the accuracy:

- Noises, shown as distortion of color or brightness of some pixels, or totally incorrect values of individual pixels that are not related to the original color. In binary images, noises are expressed inverse values as accidentally changing individual pixels. Different noise control methods have been developed in known spectral characteristics of noises. However, in practice there are no models of noisy processes, the TVIMS encounters such difficulties in the implementation of classical methods, as algorithms for processing large amounts of information about primary data and complex mathematical apparatus. Also, the existing noise leveling algorithms have such significant drawbacks, as leveling the boundaries of the images.

- Spatial transformation of object images. Such simple and high-performance methods as codes and signatures for presentation of objects for further recognition require the collection of a priori information on objects, which makes them useless during linear conversion. Different methods and tools have been proposed for rotating and turning at a particular point after orthogonal displacement to determine the turning angle of the object image. However, these methods do not contribute to improving the recognition of objects. In them, static moments are considered as the main signs of object recognition. Analysis of the works showed that in this case signs integration were high, and the accuracy of the recognition was low. It was established that the use of only existing recognition algorithms is ineffective.

- Ineffectiveness of MVO to provide invariance for multiplicative and scaling errors. Such known dimensions as Euclid, Manhattan, Canberra, Minkowski, Chebyshev provide the minimization of additive and systematic errors without correction of scale changing. The specified dimensions will be equal to zero, i.e., the known object will correspond to the standard when the multiplicative errors of the standard are equal to the multiplicative errors of the recognized object and their scale is the same. With the increase in the difference between multiplicative errors and the change in the scale of the recognized object, the value of the measurement will also increase, which is a false result.

Object recognition reliability is a key quality characterizing TGS effectiveness.

In addition to specific object image, the images included in the TGS have the noises that distort the data of the research objects and negatively affects the recognition reliability.

Images included in the TVS that negatively affect the recognition reliability and distort the features characterizing the image are subject to affin (spatial) transformations.

The presence of systematic and large-scale errors in measuring the parameters of the images of the objects reduces their recognition reliability.

As a result of the analysis, the problems raised by the study were investigated. In order to increase the recognition reliability of TGS objects, it is advisable to find a way to eliminate noise in the images of objects, develop a recognition method for objects images to be transformd by affin , and develop a MVO value expression with multiplicative and large-scale error invariance.

As a result, future research was put forward to consider the factors that influence TVIMS accuracy.

**The second chapter** deals with the development of noise elimination algorithms in binary images of objects, the determination of the change in moments of inertia in the conversion of objects images, the problems of dependence of inter-object proximity change providing approximation of the projection markers and invariance of systematic errors in space displacement:

1. Algorithm of "1" and "0" noises elimination in the image of one- and two-pixel object by measuring geometric parameters and selecting points of the image.

The state of the points surrounding it is analyzed to identify the characteristics of the central point, the perimeter element (the location of the image contour), the area element (within the image contour), or the existence of noise.

As a result, the size of the area S and the perimeter P of the object, as well as one and two pixels “0” and “1” K0 and K1 noises are obtained. In addition, the object is represented in the form of four data arrays as $A_S$, $A_P$, $A_{K0}$ və $A_P$ with the coordinates of the points having the background noise associated with the object, its contour, and noise.

It is possible to define the object form coefficients according the values of S area and P perimeter, according to the value of “0” K0 noise, the noise degree of the object, and according to the values of “0” and “1” K0 and K1 noise, the noise degree of the entire image. The expected value will be obtained on object recognition accuracy by this proposed image. The background contains useful information, so it is beyond the analysis of the image.

2. The equations of the section dimension of moment of inertia by changing the axis relative to the center of OX (horizontal) axis, M times OY (vertical) axis, N times OX and OY axis, M times OX and N times of OY axis.

In this case, the section area, the integration area, the upper integration limit for OX axis and the elemental area on the OX axis changes M times, the N times for the O axis, and the elemental area size for the OX and OY axis. The geometric dimension of the elemental field retains its coordinates when the scale changes, and the distances from the geometric centers of the elemental fields remain constant.

Determination of the inertial moment dependence when changing the size and rotating the axes, two intersecting perpendicular OU (Horizontal) and OV (Vertical) coordinate axes are rotated in the opposite direction of the counterclockwise direction towards the OX and OY axes by 0 intersection center:

$$J_{X2} = M^2 \cdot N^4 \cdot \frac{\Delta x_1 \cdot \Delta y_1^{\ 3}}{3}; \qquad J_{Y2} = M^4 \cdot N^2 \cdot \frac{\Delta x_1^{\ 3} \cdot \Delta y_1}{3};$$

$$J_{XY2} = M^3 \cdot N^3 \cdot \frac{\Delta x_1^{\ 2} \cdot \Delta y_1^{\ 2}}{4}; \qquad (2)$$

The solution of nonlinear equations system was carried out by a graphoanalytic method. The roots of nonlinear equations were found.

Methods of finding the roots of the equation system: By placing the calculated numerical values of $J_{X1}, J_{Y1}, J_{XY1}, J_{U2}, J_{V2}, J_{UV2}$ constants and evaluating variable N at interval [0;t], the graphs of the obtained equations are constructed, where t is a sufficiently large number. Considering the graphs as independent images of the curves, the intersection points with the roots of their coordinates are defined.

Determination of the values of nonlinear equations roots. Depending on the discretization frequency and the interpolation function of the variable N, the coordinates of the intersection points and so the M quantity will have approximate value.

3. One of the ways of recognizing a freely placed object in a space is to identify its two-dimensional images by comparing it with the standard.

The description of the actual object side is a closed single or multi-contoured figure, that is, the process of recognizing an object placed freely in a space can be matched by the recognition of several superficial objects in the space.

Because the surface figure is a solid object, it can be compared to the analysis of the position of the marker point placed on the surface figure.

Currently, the free positioning of the surface figure in the space and, consequently, the marker point is considered as the rotation of the surface figure with a scale change around the three coordinate axes.

An analysis of the surface figure position is carried out by analyzing the position of the marker point projection in the foreground plane. In this case, the starting point of the coordinate is placed in the center of the surface figure.

As a result, we obtain a four-equation system of equation with two unknown quantities that shows the dependence of the scale change of the surface figure around the three axis of the coordinate change of the marker point projection on the foreground surface:

$$x_2 = M \cdot x_0 \cdot \cos\gamma \cdot \cos\beta - M \cdot y_0 \cdot \sin\gamma \cdot \cos\beta \tag{3}$$

$$\begin{aligned} y_2 &= M \cdot x_0 \cdot \sin\gamma \cdot \cos\alpha + M \cdot y_0 \cdot \cos\gamma \cdot \cos\alpha \pm \\ &\pm (M \cdot x_0 \cdot \cos\gamma \cdot \sin\beta \cdot \sin\alpha - M \cdot y_0 \cdot \sin\gamma \cdot \sin\beta \cdot \sin\alpha) \end{aligned} \tag{4}$$

$$r_2 = \sqrt{M^2 \cdot r_0^2 \cdot \sin^2(\omega_0 + \gamma) \cdot \cos^2\alpha \pm \frac{M^2 \cdot r_0^2 \cdot \sin 2(\omega_0 + \gamma) \cdot \sin\beta \cdot \sin 2\alpha}{2} + + M^2 \cdot r_0^2 \cdot \cos^2(\omega_0 + \gamma) \cdot \sin^2\beta \cdot \sin^2\alpha + + M^2 \cdot r_0^2 \cdot \cos^2(\omega_0 + \gamma) \cdot \cos^2\beta} \tag{5}$$

$$\omega_2 = \operatorname{arctg}\left(\frac{\sin(\omega_0 + \gamma) \cdot \cos\alpha \pm \cos(\omega_0 + \gamma) \cdot \sin\beta \cdot \sin\alpha}{\cos(\omega_0 + \gamma) \cdot \cos\beta}\right) \tag{6}$$

where M, $\alpha$, $\beta$, $\gamma$ are the angles of rotation on OX, OY, and OZ axis, respectively.

4. Measurable physical parameters serve as the signs of images for further analysis. It is well known that measurements of any physical quantity are accompanied by the measured value of systematic errors. Known Euclid, Manhattan, Camberra, etc. measurements are mathematically justified, but they are less effective in practical terms because they have a strong dependence on systematic errors. In addition, they are less effective.

This study demonstrates its invariability to systematic errors and its prevalence in comparison with the commonly used Euclidean, Manhattan, and Canberra measurements. However, this measurement has a moderate sensitivity to the changes in the actual value of an object's parameters, and it reduces the quality of the control at the measurements require high precision. Thus, the development of invariant distance measurements with a high sensitivity to changes in the actual values of the parameters and a systematic error is an actual scientific and technical issue.

With the help of discrete cosine transformation, the distance dimensions providing the recognition of images for the second signs are solved.

The formulas of the MVO value providing invariability of object recognition and change in the actual values of the parameters to change the systematic errors of the measured values of the image and its parameters.

The arrays of the measured values of object images and the parameters of the standard can be represented in the form of single-polar periodic non-sinusoidal curves to be equally discreted. Initially, the given curves are converted into two-polarity. For this, the average value of the corresponding array is subtracted from each value of the standard and the descriptive parameters of the recognized object. The curves given by the discrete cosine transformation are then presented as numerical sequences of amplitudes ($f_x(k)$ and $f_y(k)$) of the curves of images of a well-known object known as complex numbers. Based on the obtained data, the estimation of MVO is as follows:

As a result, the following formula was obtained:

$$Z_y = \sum_{k=1}^{n-1} \left| \frac{f_{X'}(k)}{f_{X'or}} - \frac{f_{Y'}(k)}{f_{Y'or}} \right| \qquad (7)$$

where

$$f_{X'or} \neq 0 \quad \text{or} \quad f_{Y'or} \neq 0 \, . \qquad (8)$$

If (7) is not fulfilled conventionally, then formula (6) is not applied. That is, all the second signs in a recognized or standard object are equal to zero:

$$f_{X'}(1) = f_{X'}(1) = ... = f_{X'}(k) = ... = f_{X'}(n-1) = f_{X'or} = 0 \, , \qquad (9)$$

$$f_{Y'}(1) = f_{Y'}(1) = ... = f_{Y'}(k) = ... = f_{Y'}(n-1) = f_{Y'or} = 0 \qquad (10)$$

When all values of elements in X or Y arrays are equal to each other, the properties of the second signs will appear:

$$x_1 = x_2 = ... = x_i = ... = x_n \, , \qquad (11)$$

$$y_1 = y_2 = \ldots = y_i = \ldots = y_n. \quad (12)$$

The spectrum of the data array is obtained after the DCT, in which case a change in a parameter in the data array causes several amplitudes of harmonics to change in its spectrum. As a result, the changing sensitivity of initial data is increasing.

An algorithm for the selection and elimination of one- and two-pixel noises in binary images of objects is proposed. Using the 5x5 mask, one-and-two-pixel noises suppression, which provides the expected value of object recognition accuracy, and the method of selecting pixels concerning “1”, “0”, object and contour, have been determined on the proposed image.

A method for recognizing two-dimensional binary image of an object to be transformed by affin is proposed by determining the location of the object relative to the standard position. It was established that it is possible to achieve the recognition of the affine images of the objects with sufficient efficiency by considering the object’s image as a closed superficial figure and using moments of inertia as the direction of the object’s image.

A system of equations showing the dependence of the change in the coordinates of the marker point projection on the front surface during triple rotation in space and scale change is proposed. It was established that by considering the marker point as a sign of the object and using this system of equations, it is possible to recognize the object’s image with a complete set of spatial distortions, as well as identify its direction in the space.

A formula for calculating the value of the proximity dimension between objects, which provides a high sensitivity to the change in the image and its systematic errors of measured values of scale parameters and the change in invariability of object image and true values of parameters, is proposed. It was established that invariance is achieved when systematic errors and scales are compensated for by systematic errors in the value array of parameters, and the high sensitivity to the change in data is achieved by the use of second signs obtained by the discrete cosine transformation.

**The third chapter** presents computer modeling of theoretical results in the research process conducted with the help of the MATLAB program:

1. Elimination algorithm of “1” and “0” noises with one- and two-pixel was modelled on the comuter in the object image by measuring the geometric parameters presented in Chapter 2 and selecting the image points.

As a noisy image, 4 images with “1” and “0” noise of one and two pixels with a noise density of 0.01 are considered (Figure 4).

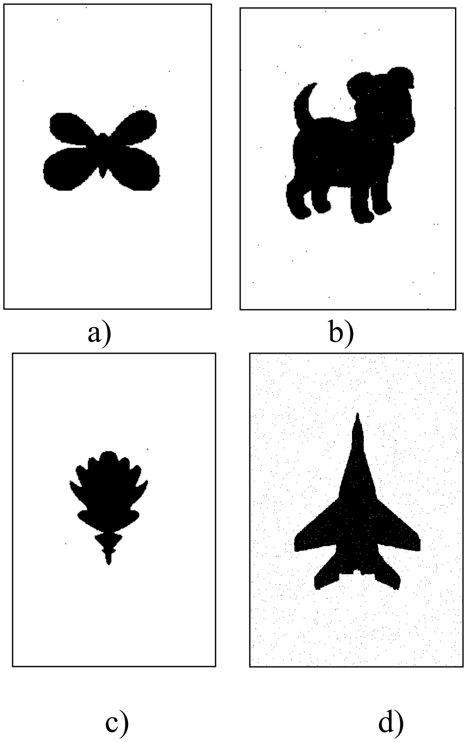


**Figure 4. an image with one and two pixels “1” and “0”**

Table 1 shows the results of each area image (S), perimeter (P), the (KO) number of “0” noise, calculation results of the (K1) number “1” noise and  the values of the relative separation between actual and calculated values of the area (ΔS) and perimeter (ΔP) for one iteration of the proposed algorithm.

**Table 1**

**Area of images, perimeter, number of “0” and “1” noises**

| Figure | S | $\Delta_S$ | P | $\Delta_P$ | K0 | K1 |
|---|---|---|---|---|---|---|
| a | 28000 | $7.1 \cdot 10^{-5}$ | 1527 | 0.1081 | 146 | 1185 |
| b | 52361 | $5.7 \cdot 10^{-5}$ | 2244 | 0.1339 | 280 | 1068 |
| c | 33748 | $1.7 \cdot 10^{-4}$ | 1685 | 0.0808 | 147 | 1131 |
| d | 19544 | $4.6 \cdot 10^{-4}$ | 1256 | 0.1144 | 92 | 1236 |

As it is seen from the table, the area is calculated with sufficiently high accuracy. The differences in the perimeter calculation are the result of adding some pixels to the perimeter, which is next to the “0” noise and placed inside the image of the object.

In order to reduce the error it is necessary to perform a double iteration of this algorithm, which takes quite a while.

In addition, $A_S$, $A_p$, $A_{ko}$ and $A_{k1}$ data arrays were obtained, in which, the coordinates of the points belonging to the object itself, its contour, the noise in the object, and background noise are recorded respectively.

1. A method of determining the direction of objects was modeled on the computer to increase the accuracy of the technical visual systems presented in Chapter 2.

In order to simplify computer modeling, stylized images of surface figures were considered.

**The first step** checked the validity of the formulas obtained by theoretical studies. Then, with the help of MATLAB program, the image scale was changed and turned to a center of mass.

**In the second** step, the binary image recognition operation method is examined by the location of a three-dimensional object in the space (Figure 5).

The algorithm of the given recognition method is also described.

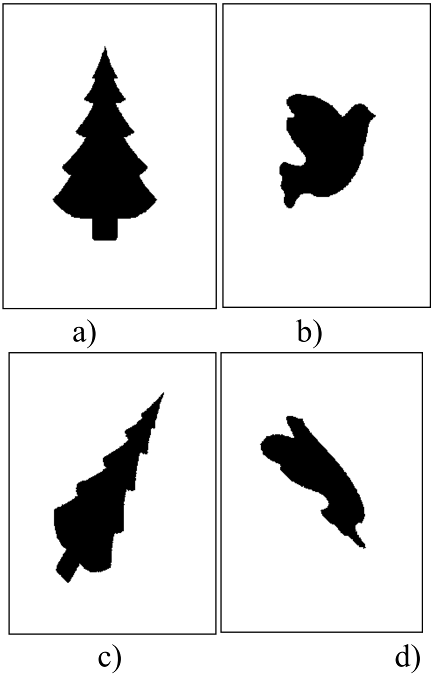


**Figure 5. Standard (a,b) and a set of the recognized images (c,d)**

The recognition process of the object will be performed by rotating the image angles φ, correcting the dimensions for M and N values, and comparing the obtained image with the standard. That is, after initial calculations, each excess position is limited. If a defined image corresponds to a standard, then it will conform to the standard after conversion.

In a completely randomly converted image, there will be no such further discretionary distortions as changing the value of individual pixels in the contour. The approximation measurement can be used as the numerical value of the similarity of the standard and the recognized image:

$$Z = \sum_{i=1}^{m} \left| \mathrm{A(x,y)_i} - \mathrm{B(x,y)_i} \right| \le \varepsilon \qquad (13)$$

$$\varepsilon = 2 \cdot P_e$$

where: $\mathrm{A(x,y)_i}$ və $\mathrm{B(x,y)_i}$ are respectively the values of the points concerning the standard and the recognized image; x, y - are the coordinates of the pixel in the image ; i - is the amount of pixels in the image; $\varepsilon$ - is the value of confidence, depending on the dimension of the images and the computational errors of the analysis; $P_e$ is the perimeter of the standard.

The given measurement shows the errors of the images, that is, the number of pixels that do not directly correspond to.

If the error for any image does not go beyond the norm, then it can be concluded that the considered side of the recognized image corresponds to that of the standard image, and in the space M, N, and φ are orientated respectively.

The results of the study showed that (13) is conditionally met for only relevant images.

1. Computer modeling was performed to check the theoretical results obtained in Chapter 2 of the investigated dependence of the marker projection on the foreground plane during displacement of the marker in the space.

On the standard image, foreground surface V is presented placed with marker points $A_1, A_2, A_3$ and $A_4$ (Figure 6).

Each marker point (x, y) has its coordinates at rectangular and (r, ω) polar coordinate system.

With the help of the AutoCAD system, the scale of this image is distorted M times around 0 point of γ angle, to the α angle around the OX axis and to the β angle around the O axis.

The results of the study showed that the obtained equations system is true for each point marker, regardless of its location in the space.

1. Computer simulation of the proposed formulas for Z MVO values was carried out with the help of the Matlab software.

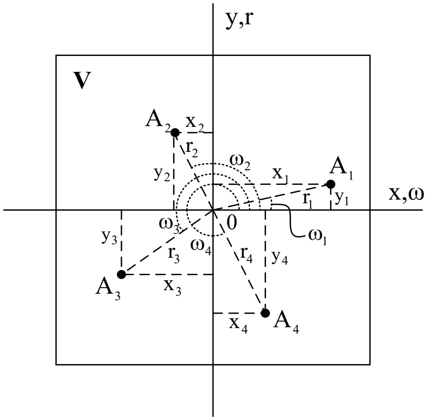


**Figure 6. Placement of the marker points on the standard image**

In order to approve the possibility of providing the invariance of systematic and scaling errors by the expression of the values of MVO parameters, in the Appendix 3, a program was presented for calculating the value of MVO in the equal values of standard images parameters by describing Euclid, Manhattan, Canberra measurements and the scale, multiplicative and additive errors of the recognized image of the object.

As it is seen in Table 2, in addition to the invariance of systematic errors of the known image of the object, the formula of the MVO Z value has the invariance of random errors, that is, the results obtained by the calculations prove the effectiveness and validity of the proposed formulas of MVO.

Computer modelling of noise elimination algorithms in binary images of objects showed its work ability and efficiency.

Computer modelling of the method defining object directions to improve the recognition accuracy of objects in technical visual systems demonstrated work ability and efficiency of the proposed method of determining the rotation angle of the known object relative to the standard point.

Computer modeling of the dependence of the change in the marker projection on the front marker during the displacement of the marker in the space confirmed the validity of the obtained formulas.

**Table 2**

**Proposed formulas of MVO value in a modified measurement of the actual value of the parameter of known distance dimensions and the recognized image of the object**

| $M_X$ | $\sigma_X$ | $\Delta x$ | $Z_{EVK}$ | $Z_{MAN}$ | $Z_{KAN}$ | Z |
|---|---|---|---|---|---|---|
| 1 | 0.01 | 0.5 | $0.0052 \cdot 10^3$ | $0.0372 \cdot 10^3$ | 0.2237 | 3.9126 |
| 1.1 | 0.011 | 0.55 | $0.0565 \cdot 10^3$ | $0.4014 \cdot 10^3$ | 2.2819 | 3.9244 |
| 1.2 | 0.012 | 0.6 | $0.1182 \cdot 10^3$ | $0.8403 \cdot 10^3$ | 4.5595 | 3.9119 |
| 1.3 | 0.013 | 0.65 | $0.1801 \cdot 10^3$ | $1.2801 \cdot 10^3$ | 6.6414 | 3.9188 |
| 1.4 | 0.014 | 0.7 | $0.2421 \cdot 10^3$ | $1.7207 \cdot 10^3$ | 8.5518 | 3.9416 |
| 1.5 | 0.015 | 0.75 | $0.3042 \cdot 10^3$ | $2.1622 \cdot 10^3$ | 10.3110 | 3.9189 |
| 1.6 | 0.016 | 0.8 | $0.3664 \cdot 10^3$ | $2.6045 \cdot 10^3$ | 11.9363 | 3.9110 |
| 1.7 | 0.017 | 0.85 | $0.4288 \cdot 10^3$ | $3.0477 \cdot 10^3$ | 13.4425 | 3.9167 |
| 1.8 | 0.018 | 0.9 | $0.4912 \cdot 10^3$ | $3.4917 \cdot 10^3$ | 14.8421 | 3.9214 |
| 1.9 | 0.019 | 0.95 | $0.5538 \cdot 10^3$ | $3.9366 \cdot 10^3$ | 16.1460 | 3.9166 |
| 2 | 0.02 | 1 | $0.6165 \cdot 10^3$ | $4.3823 \cdot 10^3$ | 17.3638 | 3.9091 |
| 2.1 | 0.021 | 1.05 | $0.6794 \cdot 10^3$ | $4.8289 \cdot 10^3$ | 18.5037 | 3.9194 |
| 2.2 | 0.022 | 1.1 | $0.7423 \cdot 10^3$ | $5.2763 \cdot 10^3$ | 19.5729 | 3.9169 |
| 2.3 | 0.023 | 1.15 | $0.8054 \cdot 10^3$ | $5.7246 \cdot 10^3$ | 20.5779 | 3.9187 |
| 2.4 | 0.024 | 1.2 | $0.8686 \cdot 10^3$ | $6.1738 \cdot 10^3$ | 21.5241 | 3.9166 |
| 2.5 | 0.025 | 1.25 | $0.9319 \cdot 10^3$ | $6.6238 \cdot 10^3$ | 22.4167 | 3.9132 |
| 2.6 | 0.026 | 1.3 | $0.9953 \cdot 10^3$ | $7.0746 \cdot 10^3$ | 23.2600 | 3.9234 |
| 2.7 | 0.027 | 1.35 | $1.0588 \cdot 10^3$ | $7.5263 \cdot 10^3$ | 24.0581 | 3.9104 |
| 2.8 | 0.028 | 1.4 | $1.1225 \cdot 10^3$ | $7.9789 \cdot 10^3$ | 24.8144 | 3.9112 |
| 2.9 | 0.029 | 1.45 | $1.1863 \cdot 10^3$ | $8.4323 \cdot 10^3$ | 25.5321 | 3.9166 |

Computer modeling of MVO values formula showed work ability and efficiency of this formula.

## MAIN FINDINGS

1. An algorithm for selecting and eliminating one-and two-pixel noises in binary images of objects is proposed. Using the 5x5 mask, the one-and-two-pixel noise elimination, which gives the expected value of object recognition accuracy, and the method of selecting pixels concerning "1", "0" noises, object and contour, have been determined.

2. A method for the recognition of a two-dimensional binary image of an object to be rotated is proposed by determining the location of the object relative to the standard position. It has been established that, by considering the image of the object as a closed surface figure and using inertial moments as the direction of the object image, it is possible to recognize the images of the objects.

3. A system of equations showing the dependence of the change in the coordinates of the marker point projection on the foreground surface during three-fold rotation in space and scale change. It has been established that by considering the marker point as a sign of the image and using this system of equations, it is possible to identify the image of an object with a complete set of spatial distortions, as well as its orientation in the space.

4. A formula for estimating the proximity between objects, which has a high sensitivity to changing object values and invariance of object image, to systematic errors of the image and its measured parameters, has been proposed. It has been established that invariance is achieved when systematic errors and scales are compensated for by systematic errors in the value arrays of parameters, and the high sensitivity to the change in data is achieved by the use of second signs obtained by the discrete cosine transformation.

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