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FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER
EDUCATION
"NORTH CAUCASUS FEDERAL UNIVERSITY"

SUGGESTIONS FOR TEACHING
to practical classes in the discipline
"Introduction to Pattern Recognition and Machine Learning"
for students of the field of study

11.03.02 Infocommunication Technologies and Communication Systems,
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INTRODUCTION

The purpose of mastering the discipline is to form students' professional competencies based on the development of modern computer vision systems, as well as the basics of system design and digital image processing that meet the requirements of professional standards and employer organizations.

Objectives of mastering the discipline:

Provide students with basic information in an easy-to-understand way about:

- modern systems of computer modeling of technical objects;
 - methods of modeling technical systems;
 - basic concepts of computer modeling of computer vision systems;
 - introduction to the theoretical foundations of methods of mathematical modeling of computer vision systems.
- detection and recognition of objects of observation in the image;
 - identification and analysis of related areas;
 - management of image processing and analysis processes.

Practical lesson No1. Investigation of the error in measuring the coordinates of point objects at linear displacements

Objectives of the work:

1. Study of matrix photodetectors as part of computer vision devices for measuring the coordinates of objects.
2. Study of theoretical issues and basic algorithms for estimating coordinates and potential accuracy of measurements based on a physical model.
3. Obtaining practical skills in working with software for recognizing objects, measuring their coordinates and estimating measurement errors.

Brief theoretical information

A modern matrix optical radiation receiver (MPEI) based on a CCD (ChargeCoupled Device) or a CMOS matrix (complementary metal-oxide-semiconductor) is not only an image or video signal generator, but can also serve as the basis for the construction of high-performance optoelectronic measuring devices and computer vision systems (CTS). Among their main advantages are the following [2, 3]:

- non-contact measurement method;
- the possibility of multi-axis and multi-channel measurements;
- use of effective algorithms for calibration and adaptation to the external operating conditions of the device;
- the ability to measure the parameters of many objects in the field of view;
- determination of parameters of extended objects;
- the ability to quickly convert coordinate systems;
- construction of large distributed measuring systems based on a network of unified computer vision devices.

The non-contact method of measurement is a consequence of the use of the principle of optical information transmission, which does not require direct interaction between the measured object and the measuring device. Information transmission is carried out by flow

optical radiation, the transmission medium is air or vacuum. In some cases, the measurement can be performed by a passive method, in which a special radiation source is not required.

The possibility of multi-axis and multi-channel measurements is associated with the multi-element structure of matrix photodetectors. In general, for each measured object it is possible to measure up to six parameters characterizing its position in space (three linear and three angular coordinates). In the case of multiple measurements, it becomes possible to additionally measure the first, second and subsequent derivatives (the rate of change of each coordinate, its acceleration, etc.) for each measured object.

As a result, it becomes possible to significantly increase the accuracy of measurements due to the initial calibration of the device, as well as periodic correction of its parameters, which are subject to changes as a result of changes in measurement conditions, degradation of the photodetector and the optical system, and other factors. Among the possible methods of calibration and adaptation, one can note the method of using tabular corrections of dark current values and sensitivity for each element; changing the parameters of the image formed by the optical system due to various types of aberrations, defocusing and vignetting.

The ability to measure the parameters of many objects in the field of view of the device is provided by the formation of a high-resolution image on the sensitive site of a multi-element photodetector. At the same time, the coordinates and geometric parameters of many radiation sources and objects whose images are present in one frame can be measured independently of each other.

Determination of such parameters of extended objects as, for example, linear and angular dimensions, deformation, shape, reflectivity characteristics, is carried out on the basis of a set of methods

image processing built on a hierarchical principle and included in the main methods of video analytics. These methods are implemented using high-performance computing tools based on digital signal processors (DSPs), which are part of network video cameras with built-in video analytics.

The ability to quickly transform coordinate systems is required in measurement systems everywhere, since the coordinate system associated with the object is the most convenient for representing its parameters, but is not related to the instrument coordinate system, which determines the position of the object image on the photosensitive surface of the IUPI. In addition, the instrument coordinate system, as a rule, uses dimensionless quantities associated with the step of the geometric structure of the photodetector elements.

Construction of large distributed measuring systems is a promising direction in measuring equipment and technology. Such systems are based on a large number of individual measuring devices (including those based on computer vision systems), which form heterogeneous measurement data that complement each other and make up a single measuring network. For this purpose, it is necessary to unify measuring parameters by transferring them from one unit to another, bringing all instrument coordinate systems to a single coordinate system, creating measuring circuits and much more.

The capabilities of the FCZ considered above are implemented provided that the main measuring parameters are provided, namely: the measurement range and measurement error of the main elements of the image.

By basic elements, we mean simple basic image details that stand out well against the surrounding background. Such elements include small-sized quasi-point images of small objects and details, thin lines, and sharp contrasting transitions between light and dark image details. Thin lines along the same coordinate can be thought of as small-sized quasi-point objects. Sharp transitions are differentiated during processing, and in this case are treated as thin lines. As a result, all three types of basic

elements of any image are reduced to varieties of a small-sized object.

An example of an ideal small-sized object is a star that is considered a point or a delta function.

It should be noted that in real optical systems, due to fundamental limitations (diffraction limit), as well as technological imperfection of optical elements, a blurry small-sized image of such an object is formed, which can most often be described as a bell-shaped function (two-dimensional Gaussian distribution or gaussoid of rotation).

The optical image in the form of a gaussoid of rotation that falls on the photosensitive surface of the MPI is converted (due to the discrete nature of the photodetector structure) into a two-dimensional matrix. The matrix is an array of samples, each of which corresponds to a charge packet of electrons, which is formed as a result of the internal photoelectric effect in each image element (pixel) and is proportional to the average illumination for each pixel. Then, depending on the technology, this charge packet is converted into an electrical video signal, which goes to the input of an analog-to-digital converter (ADC). After sampling and conversion into digital form, the video signal enters digital memory, where it is stored as a digitized image.

Thus, a digitized image in the form of a two-dimensional matrix is available for computing facilities, the dimension of which is determined by the format of the photodetector matrix of the MPAI, and the format of individual elements is determined by the bit depth of the ADC.

Methods for measuring the coordinates of small-sized objects

To assess the position of the image of an object on the photosensitive site of the MPAI, dimensionless values are used associated with the step of the geometric structure of the photodetector elements (pixels). Depending on technological and production standards, the photodetector matrix has an accuracy of positioning of individual pixels from approximately 0.2 to 0.01 μm . At the same time, the pixel size of the CMOS sensor can theoretically have the value achieved in the modern production of integrated circuits (about 0.012 μm). However, this value is significantly less than the wavelengths of the visible range (0.4 – 0.8 μm). Therefore, the pixel size is tried not to be less than 1.1 μm .

The simplest method for measuring the coordinates of a small-sized object can be based on the fact that the center of a small-sized image can be considered as the coordinate of the entire image. In this case, it is enough to determine the coordinates of the element with the maximum signal of such a small-sized image. The coordinates obtained in this way, expressed in integers, will correspond to the coordinates of the image with an accuracy of one integer element (several μm) of the photodetector matrix (with a format of several megapixels).

More sophisticated methods can significantly increase the accuracy of measuring the coordinates of the center of the image. The error can be reduced to tenths and hundredths of the step of the element. But in this case, the measurement will require much more information about the image than only about the coordinates of the largest signal of the element. The implementation of methods for measuring coordinates with subpixel accuracy is based on obtaining information about the shape of a small-sized image, which can be obtained if the image is not limited to one pixel, but is located in a neighborhood covering several pixels in each coordinate, and the image itself is formed according to a predetermined distribution law.

The most common method of measurement with subpixel accuracy is the ***weighting method*** or ***the method of determining the energy center*** of the image [4,5]. The method is based on the fact that the image of a small-sized object subject to diffraction scattering is a gaussoid of rotation. After sampling, a two-dimensional matrix is obtained on a matrix photodetector containing digitized samples from pixels that contain the signal of a small-sized object. On the other hand, too much scattering of the image will lead to the distribution of usually small radiation energy over a large number of photoreceiving pixels, which will lead to a significant decrease in the signal-to-noise ratio in the region of a small-sized image. Therefore, the optimal value of the scattering value is considered to be an area of about 5x5 pixels, in which the main part of the bell-shaped optical signal is placed.

The weighting measurement algorithm consists of several stages. At the first stage, the position of the measured small-sized image in the matrix's field of view is determined based on the simplest method for determining the coordinates of the element with the maximum signal. Then a matrix of 5x5 elements (or other selected format) is built around the previously determined maximum element. In this matrix, the elements are considered as components containing information about the coordinates and magnitude of individual elements that form the signal. Moreover, the contribution of each element to the total value of the coordinate is proportional to the signal value (element weight) [4].

Thus, it is possible to estimate the position of the energy center x of the resulting image according to the formula:

$$x = \frac{\sum_{i=x_{max}-d/2}^{d/2} (x_i E_i)}{\sum_{i=x_{max}-d/2}^{d/2} E_i}$$

where x_{max} is the horizontal coordinate (number) of the maximum element; d is the size of the neighborhood around the maximum element; E_i is the value of the element signal with the number i ; x_i is the coordinate of the element with the number i .

Accordingly, by the second coordinate y :

$$y = \frac{\sum_{j=y_{MAX}-d/2}^{d/2} (y_j E_j)}{\sum_{j=y_{MAX}-d/2}^{d/2} E_j}$$

where y_{max} is the horizontal coordinate (number) of the maximum element; E_j is the value of the element's signal with the number j ; y_j is the coordinate of the element with the number j .

The considered algorithm does not require significant computational costs. It can be implemented both on a not very productive processor and on programmable logic.

An example of a successful application of the weighting method is the measurement of the coordinates of such small-sized objects as stars. The procedure begins with obtaining black-and-white images of stars with the subsequent localization of their images against the background of noise of various physical nature. The measurement ends with the calculation of the position of the energy center of brightness of a localized group of pixels in the coordinate system of the photodetector matrix of the meter. At the same time, a large range of integral brightness of stars inevitably leads to significant differences in the accuracy of

measuring their coordinates. Model and

The calculation and analytical program Star Manager allows you to optimize the conditions for measuring the coordinates of stars of different brightness and spectral class, as well as to predict the accuracy of the result under the influence of noise [6].

Measurement accuracy can be improved by methods that use a more detailed description of the two-dimensional distribution of illumination of the image of a small object on the photodetector, as well as more information about the image obtained from the photodetector.

The most accessible method for improving accuracy is the use of *statistical estimation methods*, which are based on multiple measurements with a large number of realizations. In this case, it is possible to first estimate the probability distribution of the obtained realizations and, having estimated this distribution, choose the appropriate statistical estimation method. In most cases, the probability distribution in such measurements is reduced to a normal distribution with an unbiased estimate.

As a result, the simplest method of improving accuracy is to make multiple measurements and calculate the average value for many implementations. In most cases, the value of the measurement error decreases in proportion to the square root of the number of received implementations. For example, when 9 implementations are received and processed, the error is reduced by a factor of 3.

The method is based on the fact that the array of samples of the image elements is processed based on the approximation of the obtained signal values of individual pixels by a polynomial using the method of least squares. In this case, the obtained continuous function will correspond to the shape of the distribution of the signal in the optical image over discrete samples (after sampling on a photodetector). Naturally, the more discrete samples are used in processing, the higher the degree of the approximating polynomial can be used and the higher the accuracy of the description of the scattering function can be obtained.

The use of optimal and quasi-optimal filtering methods based on *the Kalman filter* (an iterative method for estimating image parameters) is very promising. This method involves using the image signal distribution function as a priori information, for example, a rotational gaussoid, then the discrepancy with the resulting signal realization is determined relative to the model function [7,8].

Composition of the laboratory unit

The practical lesson is carried out on the basis of a universal laboratory complex (ULK) for laboratory work on digital video equipment, image processing and video analytics, which is developed and manufactured by EVS LLC (St. Petersburg). The ULK contains a basic set of equipment, which includes an optical stand, a personal computer and a power supply. The optical stand is a metal plate on which optical and optical-mechanical equipment is installed (Fig. 1.1).

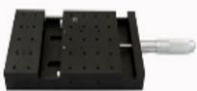


ULK

has open architecture. Open
The interface makes it as easy as possible to create original laboratory

and involves easy integration of the ULC equipment into your own projects performed in Matlab or LabView environments. The basic configuration of the ULC is presented in Table 1.1.

Table 1.1 - Composition of the universal laboratory complex

Name equipment	Appearance	Quantity	Note
Personal computer		1	with a monitor of at least 24 inches
USB camcorder		2	VEC-545-USB, 5MP
Optical bench aluminum		1	MXT120-030-12 (1200x300x12) mm
Additional fees		1	MXT030-025-12 (300x250x12) mm
50 mm micrometric movement		1	LSSP-50JV Manual Translation Stage
Stencil Holder		1	Adjustable plate holder LSGB2-7
Mounting rack		10	LSZG1-150
Laboratory illuminator		1	OI-19
Light Shielding Casing		1	(1200x300x300) mm

The basis of the hardware of the ULK is a personal computer and one or two high-resolution USB cameras.

The stand consists of the following elements: an optical table, stands for fixing cameras, a stand for fixing a stencil, micrometric movement on a stand with a radiation source, a stand with illumination, a set of test images, a light-protective casing, a power supply unit for emitters.

The ULC contains standard optical-mechanical components. Therefore, *it is possible to further expand or modify the system* by additional introduction or replacement of components, the composition of which is determined by the individual requirements of the users.

The main elements of the laboratory installation:

VEC-545 measuring TV camera with USB interface (Fig. 1.2, a); linear micrometric movement with a displacement range of 25 mm and an installation error of 0.01 mm (Fig. 1.2, b); angular micrometer movement with an angular range of 360° (Fig. 1.2, c) complete with two orthogonal linear movements; stand with a test table stencil (Fig. 1.2, d).



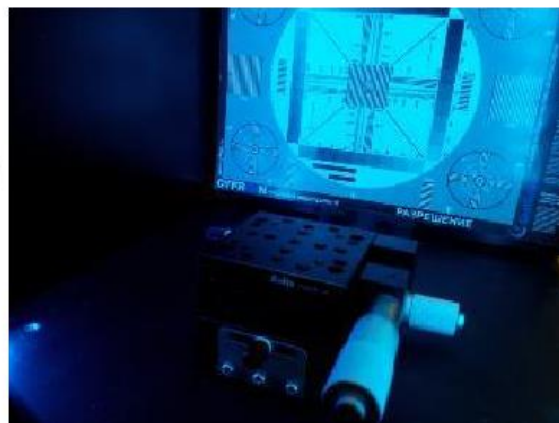
a



b



c



d

Figure 1.2 - Main elements of a laboratory installation

To perform this work, a high-resolution digital measuring video camera (5 MP) with a varifocal lens can be used, as well as a video camera with other parameters proposed by the teacher, for an extended study and comparative analysis of the results (Fig. 1.3).



Figure 1.3 - Digital measuring cameras with lenses

An LED emitter with a calibrated hole is used as a test object.

The emitter is mounted on a linear micrometer movement with manual control (Fig. 1.4).



Figure 1.4 - Micrometric Shift Emitter Adjustable power supply

provides operation and value selection current of the emitter LED. A personal computer is used to process the signal from the image of a small-sized object and conduct research as part of the work. The software used includes:

- Windows 7 or higher operating system
- Matlab software package;

- OSC16 program (manufactured by EVS LLC, St. Petersburg);
- Software files and descriptions of the basic set of laboratory work.

The video camera is connected to a computer via USB.

Procedure for performing work

1. Preparation for work

When preparing for work, you should carefully read the theoretical part. Study the composition of the laboratory installation, with the help of a teacher or laboratory assistant, turn on a personal computer and the emitter power supply.

2. Obtaining an image of an object of the desired shape

To take measurements, you need to obtain an image that is close to bell-shaped. To do this, you can use the OSC16 program. Start OSC16 on the desktop of your computer. In the window that opens, in the Settings menu item, select the Select video source item (Fig. 1.5). In the window that opens, select the EVS camera in the WDM list of the device. Click OK.

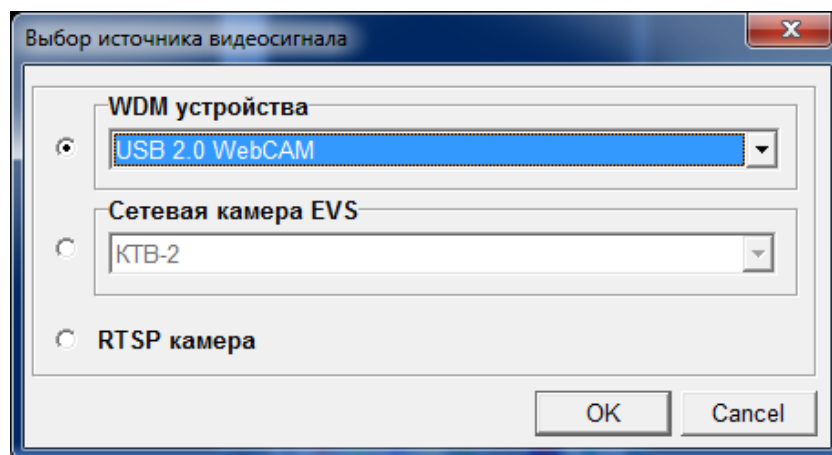


Figure 1.5 - Video Source Selection Window

In the Video Mode list of the main window, select the image format you need. Next, start the preview. Open the Magnifier, X Graph in Magnifier, Y Graph in Magnifier additional windows. Find the image of the emitter in the main window, point the cursor at it and click with the mouse. In the Magnifier window, you will see an enlarged image of the emitter (Fig. 1.6).

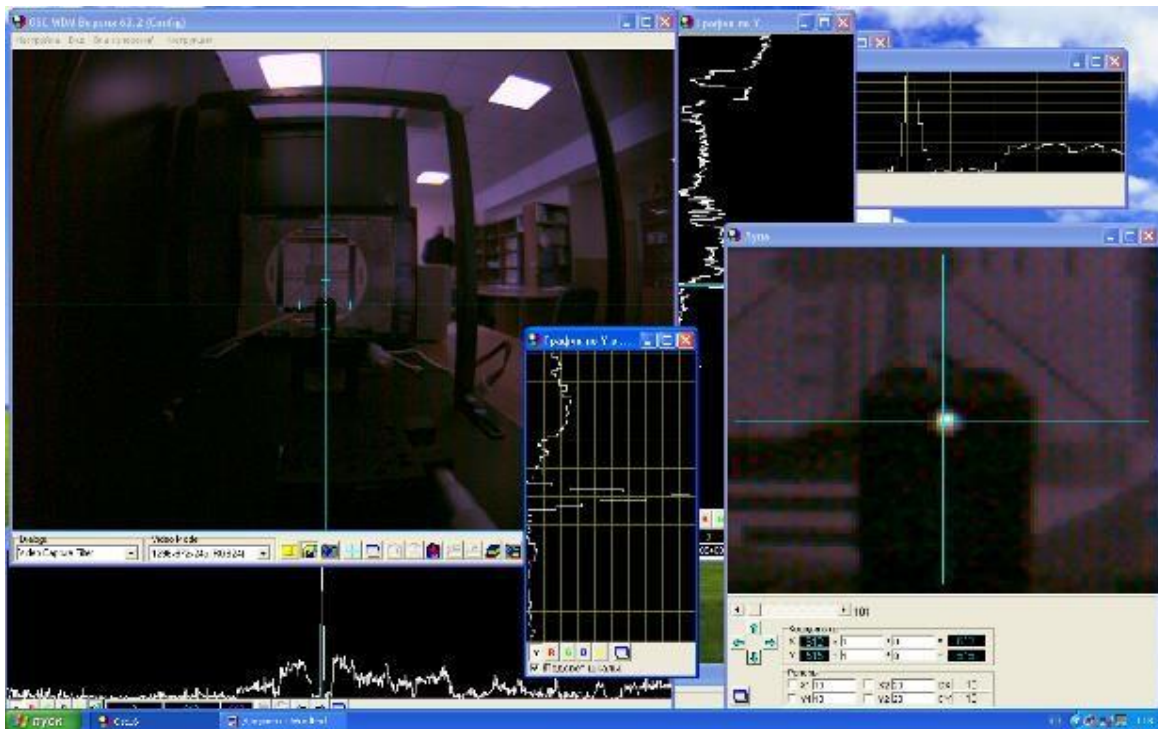


Figure 1.6 - Image of the emitter in OSC16 windows Achieve the best image

of the source in the magnifier by changing the magnify in the magnifier, and move the center of the image to the middle of the source image spot. Examine the source image waveforms in the X Graph in Magnifier and Y Graph in Magnifier windows. It should occupy approximately 5-7 pixels. If it is larger or smaller, change the focus of the lens. If the constant signal component is too large, enter the Video Capture Filter tab and open the Properties window (Fig. 1.7) with the camera settings.

Adjust the brightness to reduce the constant component to the black level. If the video signal span is insufficient, increase the supply voltage of the emitter on the power supply. After receiving the desired signal shape, close the OSC16 program.

3. Measurement of the error value in point measurements

Point measurements are performed on a stationary object in order to determine *the random component of* error. The random component of error is a set of errors determined by the presence of random processes in measurements.

Among the factors contributing to the random component, it should be noted first of all random noise of the photodetector, such as photon noise and noise of the output device.

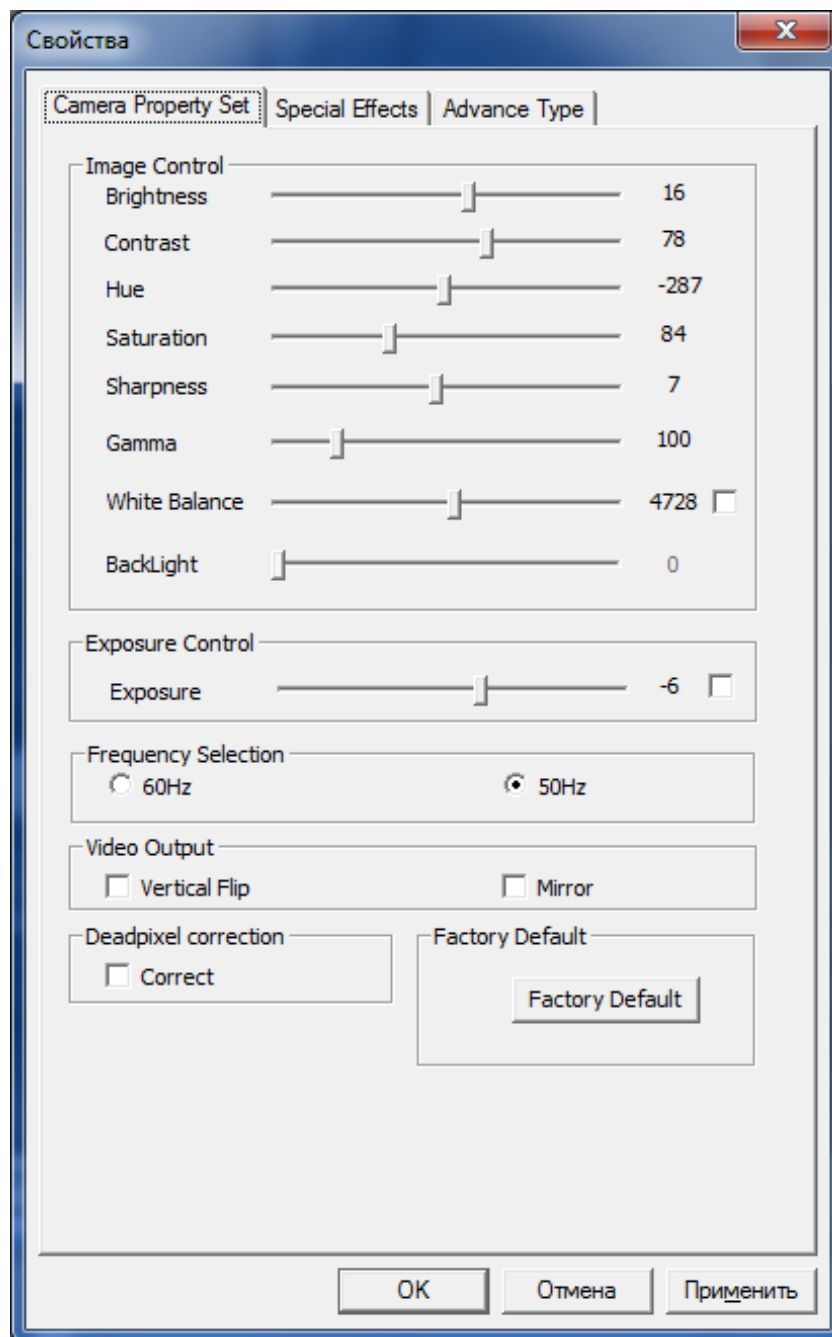


Figure 1.7 - Camera Options Properties Window

Numerically, the value of the random error of measurements can be determined by obtaining a series of measurements and further statistical processing. As a rule, the value of the random error can be characterized by the value of the standard deviation (RMS). In addition, in the process of statistical processing, it is possible to obtain the arithmetic mean value of the measurement result. To confirm the normal nature of the error distribution, it is advisable to use a graph of the probability distribution of the random process of error formation.

To estimate the RMS and the arithmetic mean of coordinate measurements, use the Matlab package. With the help of a teacher or laboratory assistant, start Matlab by clicking on the corresponding shortcut (Fig. 1.8).

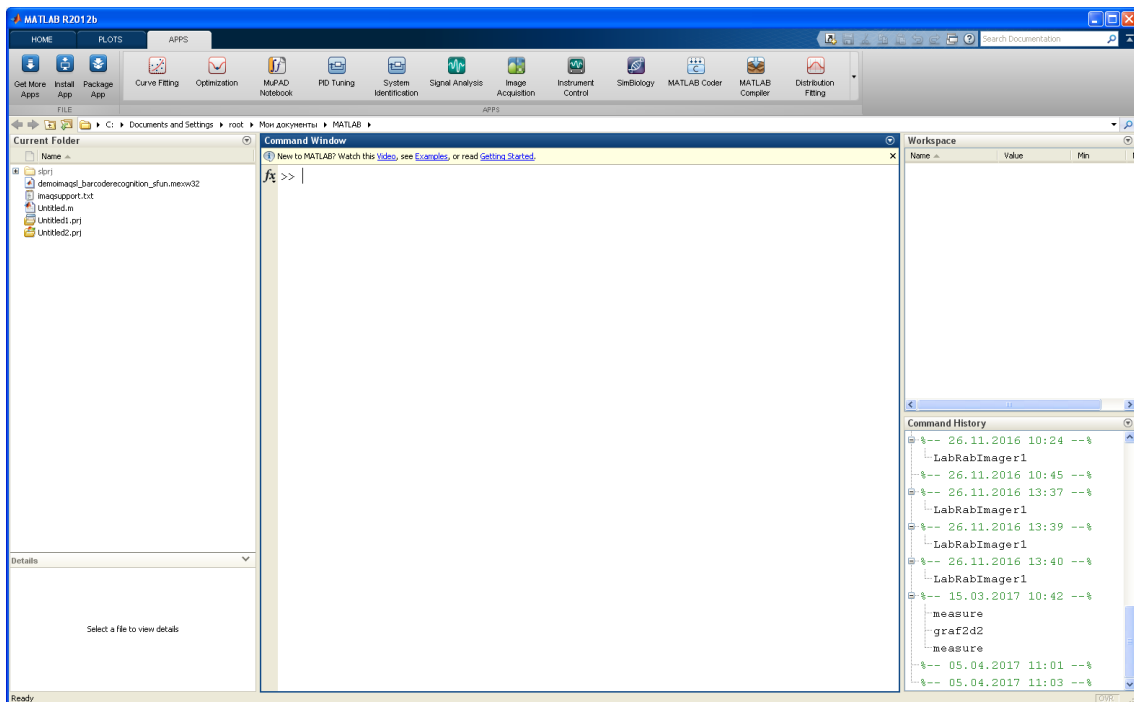


Figure 1.8 - Main window of the Matlab program

Open the file of the coordinate measurement program `measure.m` in the Matlab program. The program consists of three main parts:

1. Starting the Camera and Getting an Image:

```
vid = videoinput('winvideo', 1, 'YUY2_640x480'); % Video Stream
Definition
src = getselectedsource(vid);
vid.FramesPerTrigger = 1;
preview(vid);
```

2. Acquisition of ten realizations of digital images from the camera.

For each implementation, the primary image processing is performed, the coordinates of the maximum element in the frame are determined (small-size image search), and the two coordinates of the object are calculated using the weighting method in a given neighborhood.

```
for n = 1:10
    snapshot = getsnapshot(vid);
    ef8 = rgb2gray(snapshot); % conversion to b/w
    imshow(ef8);
    ef9 = double(ef8);
    ef9 = ef9 - 90;
```

```

% Maximum Element Position Detection
EMAX=0;
Xmax=0;
Ymax=0;
for Y = 10:630
    for X = 10:470
        if EMAX < ef9(X,Y)
            EMAX = ef9(X,Y);
            Ymax = Y; Xmax = X;
        end
    end
end
disp ('Maximum Element Position'); disp
(EMAX); disp(Xmax); disp(Ymax);
d = 8; %Scattering
%X-Weighting Calculation
x1 = 0; x2 = 0;
    for m = Xmax-d : Xmax+d
        x1 = x1 + ef9(m,Ymax)*m; x2 = x2 + ef9(m,Ymax);
    end
Xsr = x1/x2;
disp ('X coordinate');
disp (Xsr);
XX1(n) = Xsr;
%X-Weighting Calculation
y1 = 0; y2 = 0;
    for m = Ymax-d : Ymax+d
        y1 = y1 + ef9(Xmax,m)*m; y2 = y2 + ef9(Xmax,m);
    end
Ysr = y1/y2;
disp ('Координата y');
disp (Ysr);
YY1(n) = Ysr;
end

```

3. Calculate the arithmetic mean and RMS for each coordinate.

```

XXmean = mean(XX1);
YYmean = mean(YY1);
XXstd = std(XX1);
YYstd = std(YY1);
disp ('average, pix.    x    y');
disp (XXmean); disp (YYmean);

```

```
disp ('SKO, pix.      x      y');
disp (XXstd); disp (YYstd);
```

Run measure.m

At the first stage of the program, a video window for our camera should appear (Fig. 1.9).



Figure 1.9 - Preview window with camera signal

At the second stage of the program, the implementations of ten frames involved in obtaining ten samples will be obtained. The process of obtaining realizations will be accompanied by screenshots of these frames, but due to the rapid change of frames, you will see only the last of them. At the same time, for each frame, the position of the maximum element will be determined and the subsequent calculation of the coordinate of a small-sized object using the weighting method will be displayed. For all ten samples, the main measurement results will be displayed: the value of the maximum element and its coordinates, as well as the result of measurement using the weighting method. For example:

Position of the maximum element: 59; 242; 164

Coordinate x: 243.2318

Coordinate y: 165.2650

On the	the third	stage	will be
Manufactured	Statistical		Processing of measurement
results and obtaining an arithmetic mean value			

coordinates and RMS for them. The result can be seen in the main window of the Matlab program:

```
mean, pix. x y:  
243.1905    165.2922  
SKO, pix. x y  
0.1012      0.1103
```

In this example, the resulting error is approximately 0.1 pixel spacing horizontally and vertically, respectively.

Record your own results for estimating arithmetic mean values and RMS for each coordinate.

Close the video output window.

***Before another launch Programs measure.m
Always close the window with the signal output.***

4. Obtaining the static characteristic of the device

The static characteristic of the measuring device makes it possible to determine both random and systematic components of the measurement error.

A static characteristic is based on a series of measurements in which the object is shifted by an amount determined by the measurement step. In our case, it is advisable to perform measurements in increments that are approximately (5-10) % of the sensor pixel size.

As you rotate the micrometer drum upwards, set the nearest integer value on the linear motion micrometer. At the same time, try to rotate the drum only in one direction in the future. This is required to reduce the error of the emitter movement due to the influence of dead travel of mechanical movement actuators.

Start measure.m and enter the measured values of the arithmetic mean and RMS values for both coordinates in the proposed table 1.2.

By turning the drum, increase the displacement value by 0.05 mm. Start measure.m and get the values of the arithmetic mean values and RMS coordinates for the current position of the emitter and enter them in Table 1.2.

By increasing the values on the micrometer drum at each step by 0.05 mm, you get twenty realizations and enter all the measurements in Table 1.2.

Table 1.2 - Data for constructing the static characteristic of the device

N implementations	1	2	3	4	5	6	7	8	9	10
Rel. position of the micrometer	0	0,05	0,1	0,15	0,2	0,25	0,3	0,35	0,4	0,45
HSR, pix	243.1905									
SKO X, pix	0.1012									
Ycp, pix	165.2922									
SKO Y, pix	0.1103									
N implementations	11	12	13	14	15	16	17	18	19	20
Rel. position of the micrometer	0,5	0,55	0,6	0,65	0,7	0,75	0,8	0,85	0,9	0,95
HSR, pix	243.1905									
SKO X, pix	0.1012									
Ycp, pix	165.2922									
SKO Y, pix	0.1103									

5. Processing of measurement results

An example of graphs is shown in Figure 1.10. The upper graph for the X coordinate should show the dependence of the coordinate estimates in pixels on the real value of the coordinates set on the micrometer. All the obtained readings of the arithmetic mean values of the estimates for the x coordinate should be plotted on the graph and a line approximating them should be plotted.

Here you can also draw a straight line connecting the first and last measurement points. This line roughly corresponds to the ideal static characteristic of the meter, that is, the meter that has no systematic error. In our case, the systematic error will be seen as the difference between the real and ideal static characteristics.

On the graph, the RMS values at each measurement point should also be plotted in the form of segments. In this case, the middle of each segment should coincide with the value of the arithmetic mean of the coordinate value at this point, that is, with the line of the real static characteristic.

The RMS segments at each measurement point show, as a first approximation, the confidence interval for measurements.

Build similar graphs for the Y coordinate. When processing the results, the use of measurement automation using, for example, the visualization tools of the Matlab package is encouraged.

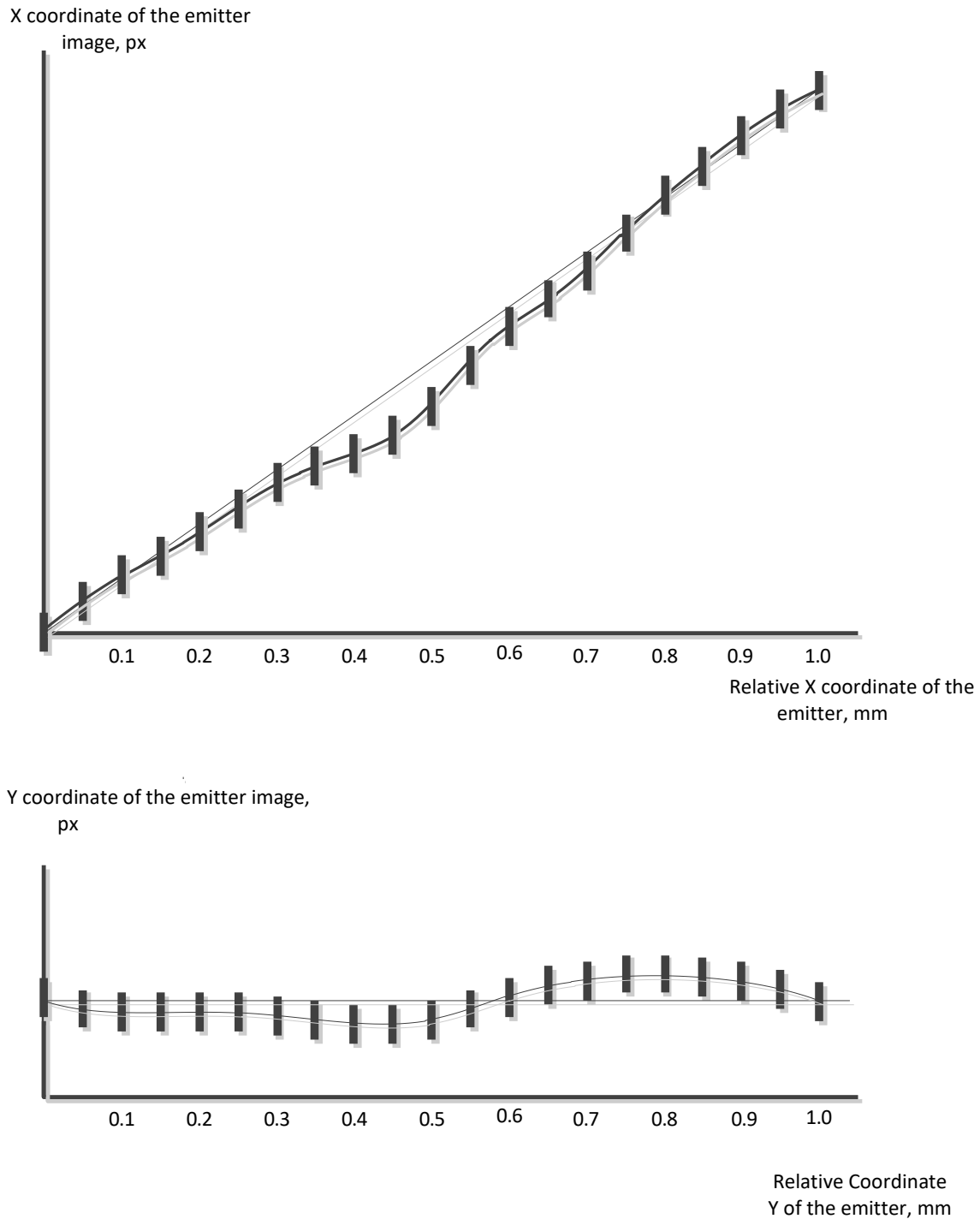


Figure 1.10 - Example of graphs of a static characteristic

Calculating the focal length of a lens

A method was used in which the obtained values are dimensionless and expressed in the number of periods of the matrix structure of the photodetector (pixels). To calculate the linear displacement of the image on a photosensitive surface, it is necessary to know the pitch of the matrix elements and the focal length of the lens.

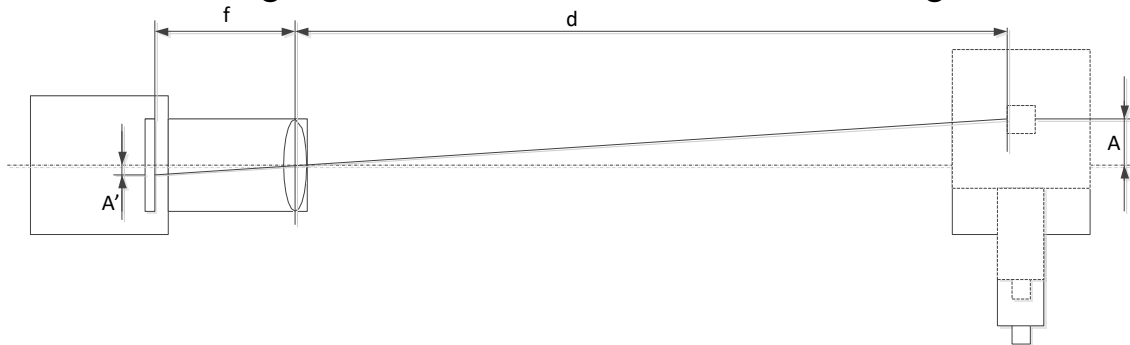
To approximate the focal length of a video camera lens, you can use the thin lens formula:

$$\frac{1}{d} + \frac{1}{f} = \frac{1}{F};$$

where F is the focal length, mm; d is the distance from the object to the outer surface of the optical system (lens), mm; f is the distance from the objective to the photodetector, mm.

The distance from the object to the objective d can be measured directly on the laboratory setup, the distance from the objective to the optical image plane (to the matrix) f is difficult to measure, but it can be roughly calculated using the principle of similarity of triangles (Fig. 1.11).

Figure 1.11 - To the determination of focal length



If we can determine the displacement of object A and the corresponding displacement of the image A' , then from the formula of proportion

$$\frac{f}{A'} = \frac{d}{A}$$

Convert the dimensionless units of displacement of the image A' , expressed in the number of pixels, to the linear displacement dimension expressed in units of length.

In this work, we use a VEC-545 camera based on a photosensitive CMOS sensor model OV5620 with a format of 2592x1944 (5 megapixels) and square pixels of 2.2x2.2 μm [9]. Calculate the focal length of the lens using the known parameters and measurement results. To determine the value of A and the corresponding value of A' , it is better to use the end readings (1st and 20th) obtained when constructing the static characteristic of the meter in paragraph 4 of the description of the work.

Calculation of measurement error

Calculate the measurement error value in object space using *the values f and d* , as well as the known value of the coordinate error in the image plane, expressed in pixels, and the spacing of the matrix elements.

Contents of the report

1. Brief information about methods for measuring the coordinates of small-sized objects.
2. Information on preparatory work for measurements.
3. The results of the work in the form of screenshots of software windows and the data obtained, auxiliary and summary tables with the results of observations and measurements.
4. Results of processing the data obtained: static characteristics of the meter, assessment of the error of deviation of graphs from linearity, calculations of meter parameters.
5. Brief conclusions on the work.

Control questions

1. How can I use a video camera to take measurements?
2. What factors determine the measurement error?
3. What is the main method for taking measurements with sub-pixel accuracy?
4. How are multi-channel measurements implemented?
5. How can you determine the focal length of a lens?

Practical Lesson No2. Study of Sensitivity Uniformity of a Matrix Photodetector

Objectives of the work:

1. Study of the theoretical foundations of calibration of computer vision systems and methods of algorithmic correction of components "geometric" noise of the matrix receiver of optical radiation (MPEI).
2. Acquisition of practical skills in working with control and measuring equipment to identify the polarization sensitivity of the photodetector.
3. Determination of the dependence of the multiplicative component of noise on the spatial orientation of the plane of the matrix receiver and identification of quantitative differences between the signal taken from the central region of the receiver and signals taken from the peripheral regions.

Brief theoretical information

"Geometric" noise of a matrix photodetector

When designing optoelectronic vision systems, it is necessary to take into account a significant number of factors related to physical processes that occur in different links, in particular: input optical effects of observed objects and background interference; processes associated with the formation of a charge relief in the photodetector, taking into account internal non-stationary noise; distortions resulting from the conversion and quantization of signals in the ADC unit at a limited bit width [10].

Modern multi-element photodetectors based on solid-state matrix converters (CCD and CMOS sensors) are highly sensitive due to their internal structure. The sensory elements spatially distributed over the sensor area are characterized by individual optical and electrical characteristics. This leads to an uneven response of pixels under optical exposure and manifests itself in the form of "geometric" noise, which is absent in devices based on single-element receivers. "Geometric" (or structural) noise leads to a decrease in image contrast and contributes

Contribution to the overall instrumental error of the measuring instrument in the analysis of the irradiation distribution over a photosensitive site, e.g. in video polarimetry or in photon counters based on CMOS technology.

When implementing high-precision instruments and systems based on MPEI, it is necessary to take into account the presence of the following components of "geometric" noise:

- additive (due to the unevenness of the average density of dark accumulation currents across the crystal); it is manifested by the standard deviation of the number of "thermal" charges in the storage cells of the matrix from the average value for the crystal;
- multiplicative (due to the non-uniformity of sensitivity within the matrix working platform); it is manifested by the root mean square values of fluctuations in the number of charges formed in pixels under the influence of background radiation, and the number of signal charges in the cells of the matrix.

These components of spatial noise are amenable to hardware and software linear correction and can be minimized by post-processing of the resulting image based on digital signal conversion from each pixel of the matrix. Individually selected coefficients are loaded into the computer memory after the calibration program is launched [12,13,14].

Technological capabilities for reducing structural noise from the dispersion of MPEI pixel parameters are limited. Therefore, the detection conditions can be improved by increasing the signal-to-noise ratio by increasing the size of the matrix photocells and the operating voltages of the reading circuit, as well as by implementing algorithms for automatic correction of the inhomogeneity of the read images by software [15,16].

Algorithmic correction of the geometric noise of the MPOI in some cases is insufficient. The reasons for this are as follows: discrepancy between the real parameters of the receivers and the parameters of the linear model, changes in the parameters of the receivers after the last calibration, imperfection of the radiation source, which leads to heterogeneity of the illumination of the receiver site during its calibration [17].

Correction of the additive component of "geometric" noise

The signal in the elements of the matrix is formed as a result of two processes — photogeneration and thermal generation. In both cases, the mechanism

Similar. Photogeneration forms Useful Signal and noise (accidental Component – photonic noise, deterministic — Includes in additive component geometric noise). The law of photogeneration formation is proportionality to the quantum yield. Thermal generation (as a result of thermal processes in a photodetector) depends as a fourth degree on temperature. Therefore, cooling is used in good systems. The thermal generation signal can be considered How to analogue photogeneration, i.e. Available Constant component ("useful signal" thermal generation) and Noise component: the random component is an analogue of photon noise, defined as the square root of the signal, and the deterministic component is the part of geometric noise. The proportion of these two components of noise depends mainly on temperature. For a more accurate definition of "geometric" noise Linear two-point correction is used [18,19, 20].

To estimate the additive component of the "geometric" noise, the coefficient of relative dispersion of the values of the dark accumulation current density over the hT crystal is used:

$$\sigma D = \overline{q_{ThT}},$$

where $qT = i_{TA} t / e$ is the average number of dark charges in the crystal (Fig. 2.1), which accumulate in the cells due to the thermal generation of carriers in the accumulation cycle; A is the pixel area, t is the charge accumulation time, e – electron charge; iT is the average value of the dark current in the crystal; the value of hT is determined by the expression:

$$hT = \frac{2 (qT_{max} - qT_{min})}{3 (qT_{max} + qT_{min})}$$

where qT_{max} and qT_{min} are the minimum and maximum values of dark charges, respectively. At the stage of calibration of the optoelectronic system at a given temperature of the receiver crystal, a correction matrix [Tg] of the following form can be obtained:

$$[Tg] = \begin{bmatrix} \overline{t1.1} & \dots & \overline{t1.M} \\ \vdots & \ddots & \vdots \\ \overline{tN.1} & \dots & \overline{tN.M} \end{bmatrix}.$$

Each element of the matrix is calculated as follows:

$$\overline{ti.j} = \frac{\sum_{n=1}^K ti.j}{K},$$

where ti,j is the numerical value of the "dark signal" of the i-th element of the j-th string retrieved in n implementation; K – the number of sales for which averaging is carried out at this stage of calibration.

If it is necessary to take into account the temperature of the matrix, the numerical values of the elements of the conversion matrix can also be adjusted in accordance with the change in the operating temperature of the crystal [19, 20].

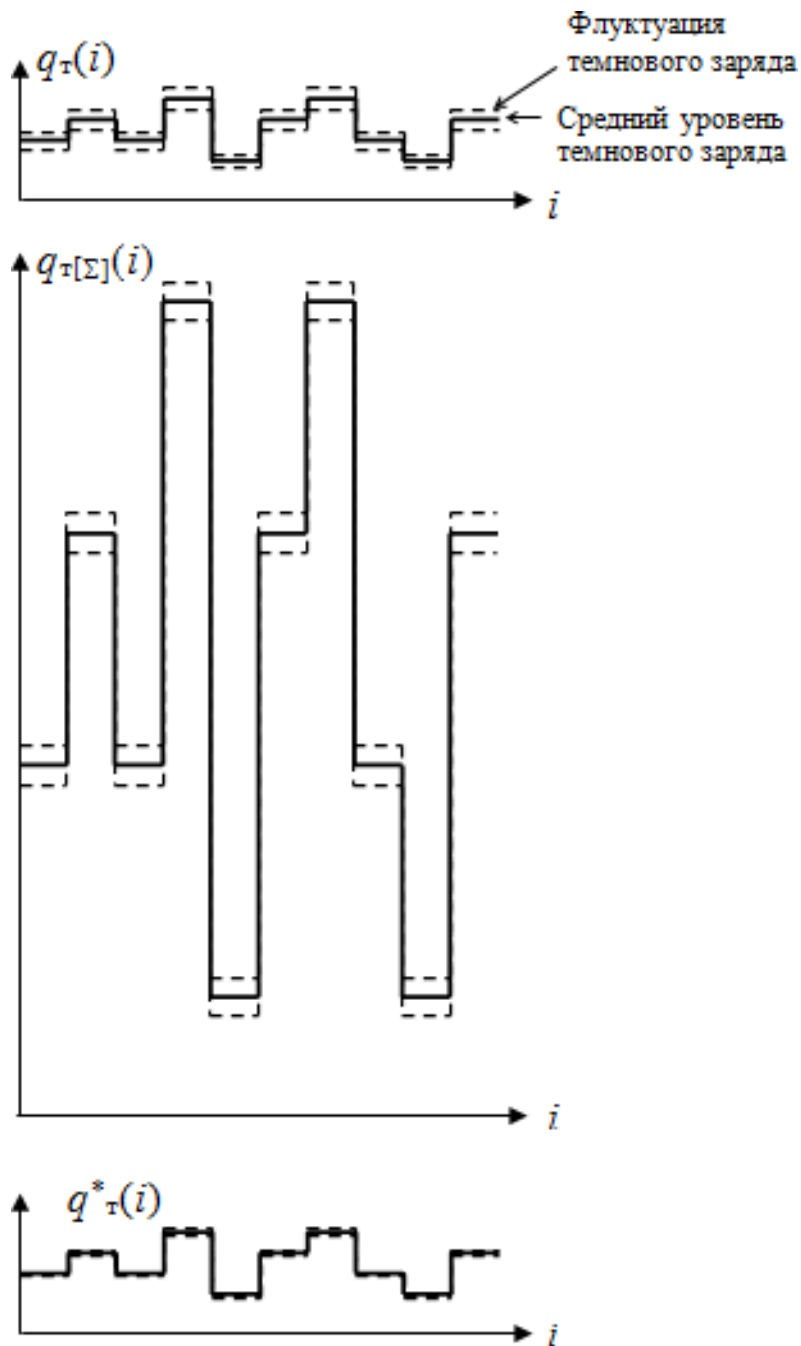


Figure 2.1 – Correction of the additive component "geometric" noise

Therefore, if the unevenness of the average density of dark accumulation currents on the iT crystal to be considered additive interference, then the correction method can be represented as the algorithm presented below:

$$[Eq_i] = [E_{im}] - k(\Delta T) \cdot [Tg],$$

where $[E_{ci}]$ is the digital image matrix after the correction procedure geometrical noise; $[E_{im}]$ is the initial matrix of the digital image; $k(\Delta T)$ is the correction factor to take into account the dependence of the conversion on the temperature change of the average values of the dark accumulation current density for the semiconductor material of a given receiving device (Fig. 2.1).

Methodology Adjustments additive component "geometric noise" consists in the fact that initially in the cycle there is an accumulation of N frames from 1 to K (Fig. 2.2). Next, a digital array $[T_{i,j}^{(N)}]$ is introduced, which, in turn, has an average level of signal charge, as well as fluctuations of this charge located between the average level.

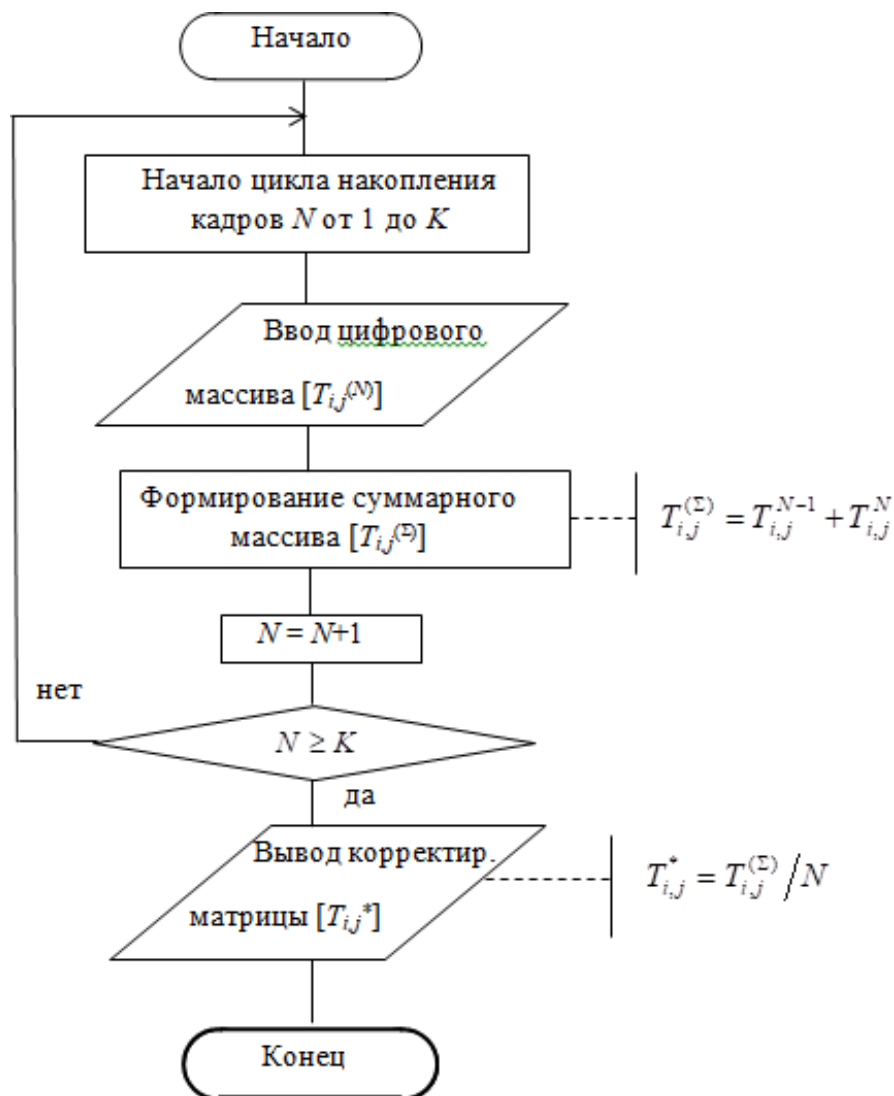


Figure 2.2 – Block diagram of the algorithm implemented at the stage of formation of the correction matrix of the additive component of the "geometric" noise

Then the total array is formed

$$T_{i,j}^{(\Sigma)} = T_{i,j}^{N-1} + T_{i,j}^N$$

This eliminates fluctuations in the dark charge and increases the average signal charge level. Next, the $N \geq K$ condition is checked and a correction matrix is derived

$$T_{i,j}^* = T_{i,j}^{(\Sigma)} / N$$

The algorithmic correction of the considered component is the most effective, since the non-uniformity of the density of "dark" accumulation currents over the crystal is an additive interference determined for each specific sample of the MPEI.

Corrections multiplicative component "geometric" noise

When implementing high-precision instruments and systems, in addition to the above-mentioned additive component of "geometric" noise, it is necessary to take into account the coefficient of relative dispersion of sensitivity of individual elements within the crystal.

$$h_s = \frac{2}{3} (S_{\max} - S_{\min}) / (S_{\max} + S_{\min}),$$

where $S_{\min}$ and $S_{\max}$ are the minimum and maximum values of integral sensitivity, respectively.

Unevenness of absolute sensitivity within the working area of the matrix receiver can cause an additional *multiplicative* component of the "geometric" noise, as the signal values of the $\bar{q}C$ may differ from element to element even with absolutely uniform background radiation in the system's field of view (Fig. 2.3). However, taking into account the deterministic nature of this interference (for this particular sample of the receiver), the following correction algorithm can be applied [21].

When the receiver is calibrated, a correction matrix is formed

$$[S] = \begin{bmatrix} S_{1,1} & S_{1,2} & \dots & S_{1,M} \\ S_{2,1} & S_{2,2} & \dots & S_{2,M} \\ \vdots & \vdots & \ddots & \vdots \\ S_{N,1} & S_{N,2} & \dots & S_{N,M} \end{bmatrix}$$

Each element of the matrix is calculated as a ratio of

$$S_{i,j} = N_{o,j} / E_{max},$$

where $E_{i,j}$ is the value of the signal of *the i-th element* of *the j-th line* (expressed in numerical form) with uniform illumination of the working platform of the MPEI

calibration background signal; E_{max} is the maximum signal value taken from the total number of elements of the original matrix $[E_{i,j}]$ in the $M \times N$ format.

$$E_{i,j}^{**} = E_{i,j}^* S_{i,j},$$

wh $E_{i,j}^*$ – the values of the elements of the digital image after the procedure
ere

correction of the additive component of "geometric" noise.

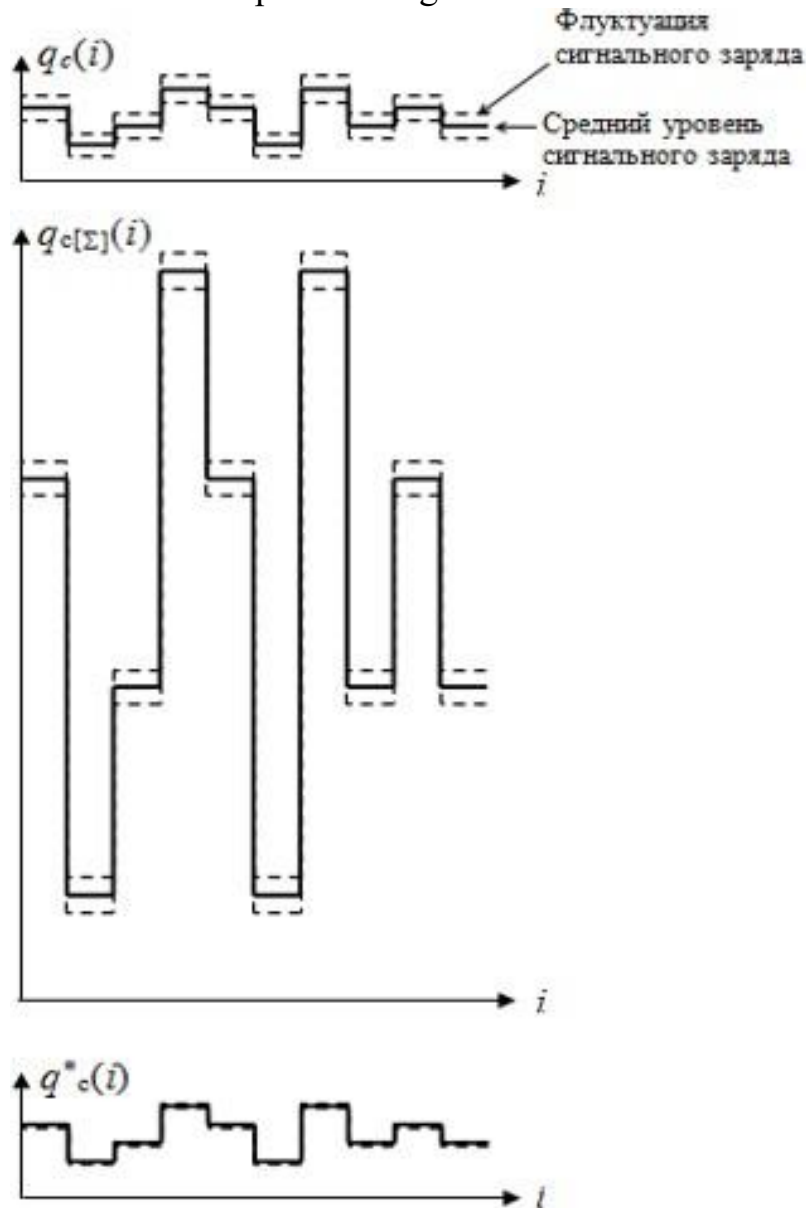


Figure 2.3 – Correction of the multiplicative component
"geometric" noise

The method of adjusting the multiplicative component is that initially in the cycle there is an accumulation of frames N from 1 to K

(Fig. 2.4). Next, a digital array $[S_{i,j}^{(N)}]$ is introduced, which in turn has an average level of signal charge, as well as fluctuations of this charge, located between the average level. After that,

Subtraction additive component Forest $S_{i,j}^{(N*)} = S_{i,j}^{(N)} - T_{i,j}^*$ Then

A total array is formed $S^{(\Sigma)} = S^{(N*-1)} + S^{(N*)}$, the i,j i,j i,j
thereby the fluctuations of the "dark" charge are eliminated.

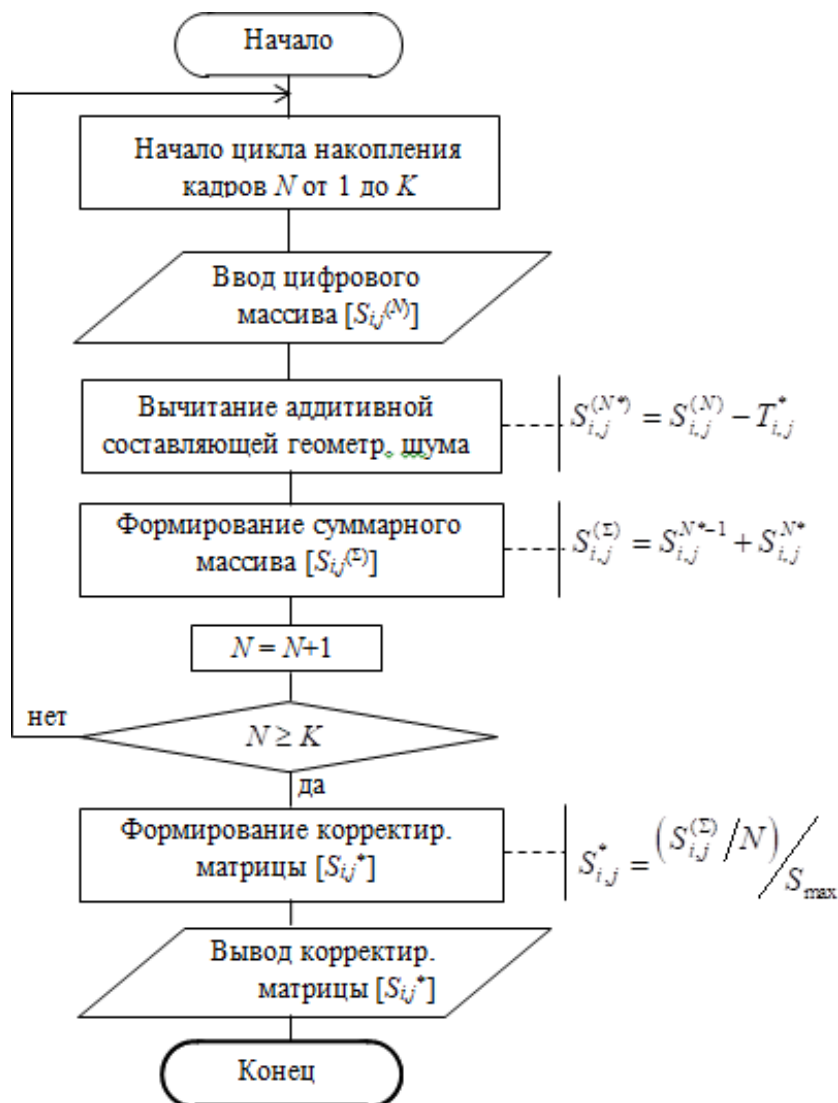


Figure 2.4 – Block diagram of the algorithm implemented at the stage of formation of the correction matrix of the multiplicative component "geometric" noise

Polarization sensitivity of MPEI

Polarization sensitivity in photodetectors based on isotropic semiconductors occurs in cases where the orientation of the plane of the photosensitive element relative to the optical axis is different from normal. All pixels of a multi-element receiver have their own optical and geometric

parameters. Technologically, it is almost impossible to create two pixels that are exactly the same. Therefore, it can be assumed that the polarization sensitivity will be different for each pixel, since it depends on the parameters of the pixels.

The energy transmittance of each interface of the media of the multilayer structure of the photodetector pixel is described by an expression of the form [22, 23]

$$T = \frac{n_2 \cos \alpha''}{n_1 \cos \alpha} (t_{2s}^2 \cos^2 \alpha_{in} + t_{2p}^2 \sin^2 \alpha_{in}) = T_{2s}^2 \cos^2 \alpha_{in} + T_{2p}^2 \sin^2 \alpha_{in}, \quad (2.1)$$

where α is the angle of incidence of radiation at the interface of two media, α'' is the angle of refraction, N_1 and N_2 are the refractive indices of the media before and after the interface, respectively; T_s and T_p are the energy transmittances for radiation polarized perpendicular and

parallel to the plane of incidence of radiation, respectively; α_{in} – azimuth

Polarization of incident radiation, T_s and T_p are the amplitude transmittance of mutually orthogonal components of radiation, which are located according to Fresnel formulas:

$$t_s = \frac{2n_1 \cos \alpha}{n_1 \cos \alpha + n_2 \cos \alpha''}, \quad t_p = \frac{2n_1 \cos \alpha}{n_2 \cos \alpha + n_1 \cos \alpha''}. \quad (2.2)$$

Let us consider the relations that determine the relationship between the output signal of a pixel and its optical properties. The value of the signal charge taken from an individual pixel is determined by the expression:

$$q = \frac{iAt}{e}, \quad (2.3)$$

where A is the area of the pixel, t is the time of charge accumulation, e is the charge charge;

i is the photocurrent at the output of the sensory element of the matrix:

$$i = \frac{EBL}{h\nu} F'' = \frac{EBL}{h\nu} T(\alpha, \alpha_{in}) F,$$

where η is the quantum efficiency of the photodetector; β is the separation coefficient of charge carrier pairs; h is Planck's constant; c is the speed of light in a vacuum; λ is the wavelength of radiation; α is the angle of incidence of radiation at the interface of media; F and F'' are the radiation fluxes of the incident and transmitted waves, respectively.

From the expressions (2.1) and (2.3) it follows:

$$i(\lambda, \varepsilon, \alpha) = \Phi \frac{e\eta\beta\lambda}{hc} \left[T_p(\varepsilon) \sin^2 \alpha + T_s(\varepsilon) \cos^2 \alpha \right] \quad (2.4)$$

Thus, the sensitivity of the MPOI is characterized by two values: to radiation polarized in the plane of incidence (sp) and in the plane perpendicular to the plane of incidence (ss). Normalized dependence of sensitivity on the angle of incidence is calculated according to the following formulas:

$$s_p(\varepsilon) = \frac{n^2 \cos^2 \varepsilon}{n l \cos \varepsilon} t_p^2, \quad s_s(\varepsilon) = \frac{n^2 \cos^2 \varepsilon}{n l \cos \varepsilon} t_s^2 \quad (2.5)$$

The main parameter of a polarization-sensitive photodetector is the effective polarization sensitivity, which is defined as the difference between the p - and s -components:

$$\Delta S(\lambda, \varepsilon) = S_p(\lambda, \varepsilon) - S_s(\lambda, \varepsilon) = \frac{e\eta\beta\lambda}{hc} [T_p(\varepsilon) - T_s(\varepsilon)]$$

This formula relates the sensitivity of the photodetector to the transmittance and the angle of incidence of radiation at the interfaces of the optical media that form it. The amplitude of the signal is proportional to this value, therefore, it depends on the refractive indices and transmittance of the crystal; azimuth of polarization, angle of incidence and wavelength of radiation.

The manifestation of the sensitivity of a photodetector to changes in the polarization state of incident radiation can be used to study the inhomogeneity of the spatial distribution of the absolute sensitivity of multielement photodetectors.

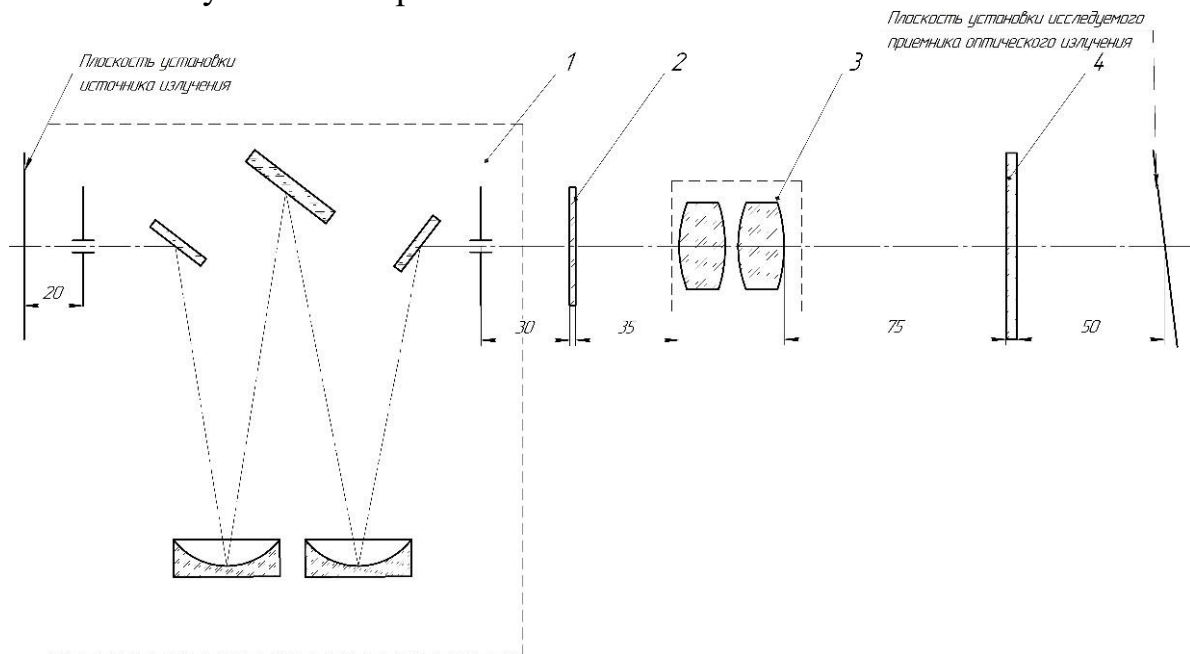
Structure of Laboratory Bench for Sensitivity Study of Matrix Photodetector

The expediency of studying geometric noise is associated with the need to use calibrated MPOI in high-precision computer vision devices.

The optical schematic diagram of the laboratory stand for studying the sensitivity of matrix optical radiation detectors (Fig. 2.5) consists of an optical radiation source, 1 – a monochromator; 2 – ground glass; 3 – a collimator; 4 – a polarizer and a multi-element photodetector under study.

Radiation from the source passes through the optical scheme of the MDR-206 monochromator and is scattered on ground glass for uniform distribution of irradiation in the plane of the collimator's diaphragm. After the collimator, a parallel beam of light passes through the polarizer and acquires linear polarization, after which it hits the matrix of the color video camera, which, at an angle to the incident radiation, becomes sensitive to changes in radiation polarization. Through the USB port of a personal computer, power is supplied to the video camera and its output signal is recorded. A program is installed on the PC that allows processing the signal from the camera pixel-by-pixel.

Figure 2.5 – Optical diagram of the laboratory bench for studying the sensitivity of matrix optical radiation receivers



All elements of the stand are attached with the help of racks to an optical rail. The distances between the elements of the circuit are selected taking into account the design and ergonomic requirements.

A halogen lamp (OSRAM 12V, 20W, 350–3500 nm) is used as a radiation source in the small-sized illuminator of the MDR-206 monochromator, the radiation from which is directed to the inlet slit using a condenser (mirror spherical mirror, $f''=101.5$ mm). The MDR-206 monochromator is built according to the Ebest-Fasti scheme, which uses two spherical mirrors, which makes it possible to reduce overall dimensions and increase dispersion [23].

A monochromator is not a measuring instrument and is designed to produce monochromatic radiation in a wide spectral

range. The dispersing element of the monochromator implements spatial optical filtering of radiation.

The MDR-206 monochromator uses replaceable diffraction gratings, their characteristics are given in Table 2.1, the gratings operate in the first order of the spectrum.

Table 2.1 – Parameters of diffraction gratings [23]

Number of strokes per millimeter	1200	600	300
Spectral operating area, nm	200-1250	380-2500	760-5000
Maximum energy region, nm	500	1000	2000
Inverse linear dispersion, nm/mm	4,3	8,6	17,2

As a result of diffraction, a system of parallel monochromatic beams is formed, which are directed into the plane of the output slit by means of spherical and rotary mirrors. The spectral interval $\delta\lambda$ generated by the monochromator varies in different spectral ranges and depends on the size of the instrument output slit width and linear dispersion. The technical parameters of the monochromator are presented in Table 2.2.

Table 2.2 – Technical parameters of the MDR-206 monochromator [23]

Parameter	Significance
Spectral range, nm	190-5000
Focal length of spherical lenses, mm	180
Relative Aperture	1:4
Slit opening range, mm	0 - 4,2
Counting accuracy, mm: at opening 0 - 0.2 mm when opening 0.2 – 4.2 mm	0,001 0,01
Nutrition	$\sim(220\pm22)V, (50\pm1)Hz$

Before starting the experiment, it is necessary to set the size of the slits of the monochromator so as to match the size of the monochromatic image with the size of the input slit. The decrease in the width of the image of the slit S^* in the focal plane is associated with a decrease in the width of the input slit of the monochromator. To correctly select the size of the input slit, it is necessary to take into account the value of the normal width of the input slit S_0 of the monochromator, which is equal to

$$S_0 = f_1 (\lambda/d_1), \quad (2.6)$$

where f_l is the focal length, d_l is the light diameter of the collimator, λ is the measured wavelength, mm .

Reducing the size of the input slit so that its current size satisfies the $S < S_0$ condition does not change its image width S^* , which will remain constant due to the diffraction of the radiation at the aperture of the dispersing element.

If the width of the inlet slit is greater than the width of the normal slit $S \gg S_0$, then the effect of diffraction and aberrations on the image size of the inlet slit in the focal plane can be neglected. In this case, the image of the exit slit is represented as a rectangle with a width of S^* . Then, in the length region in the focal plane, for the exit slit of size S_2 , provided that $S_1 = S_2$, the spectral interval allocated by the exit slit can be calculated

$$\delta\lambda = S_2 (d\lambda/dl), \quad (2.7)$$

where S_2 is the working width of the spectrophotometer output slit, $d\lambda/dl$ is the inverse linear dispersion of the monochromator.

Before carrying out spectral measurements, the value of the normal slit width S_0 is calculated according to formula (2.6). Next, the width of the input slit S_1 of the monochromator is chosen so that its size meets the conditions $S \gg S_0$. Next, the spectral range of wavelengths $\Delta\lambda$ allocated by the output slit S_2 is estimated taking into account the formula (2.7).

The wavelength indicator and control buttons are located on the front panel of the monochromator. In the manual stepper motor mode, special buttons are used to rotate the diffraction grating, and a computer connector is provided in the design of the device for automatic data recording.

A M13VM550 lens located in the reverse course of the beams is used as a collimator of the stand (Table 2.3).

Table 2.3 – Lens parameters M13VM550

Parameter	Significance
Format	1/3"
Mounting Type	CS
Focal length, mm	5-50
Relative Aperture	F1.0-close

The receiving device and the object of study in the scheme is the VEC-545-USB video camera based on the CMOS sensor, the characteristics of which are presented in Table 2.4.

Table 2.4 – VEC-545-USB Camera Specifications [9]

Parameter	Description
Matrix type, model, format	OmniVision OV5620, CMOS, 1/2,5"
Number of active elements	2592 (mountain) x 1944 (ver.)
Pixel size, μm	2.2 (h) x 2.2 (h)
Sensitivity, $\text{mV/lx}\cdot\text{s}$	500
Minimum working illumination, lx	0,5
Maximum working illumination, lx	100000
Voltage (from USB 2.0 port), V	5
Current consumption, mA	140
Lens type	C/CS
Camera dimensions, mm	50x57x57

The spectral distribution of the sensitivity of the receiver under study is shown in Figure 2.6.

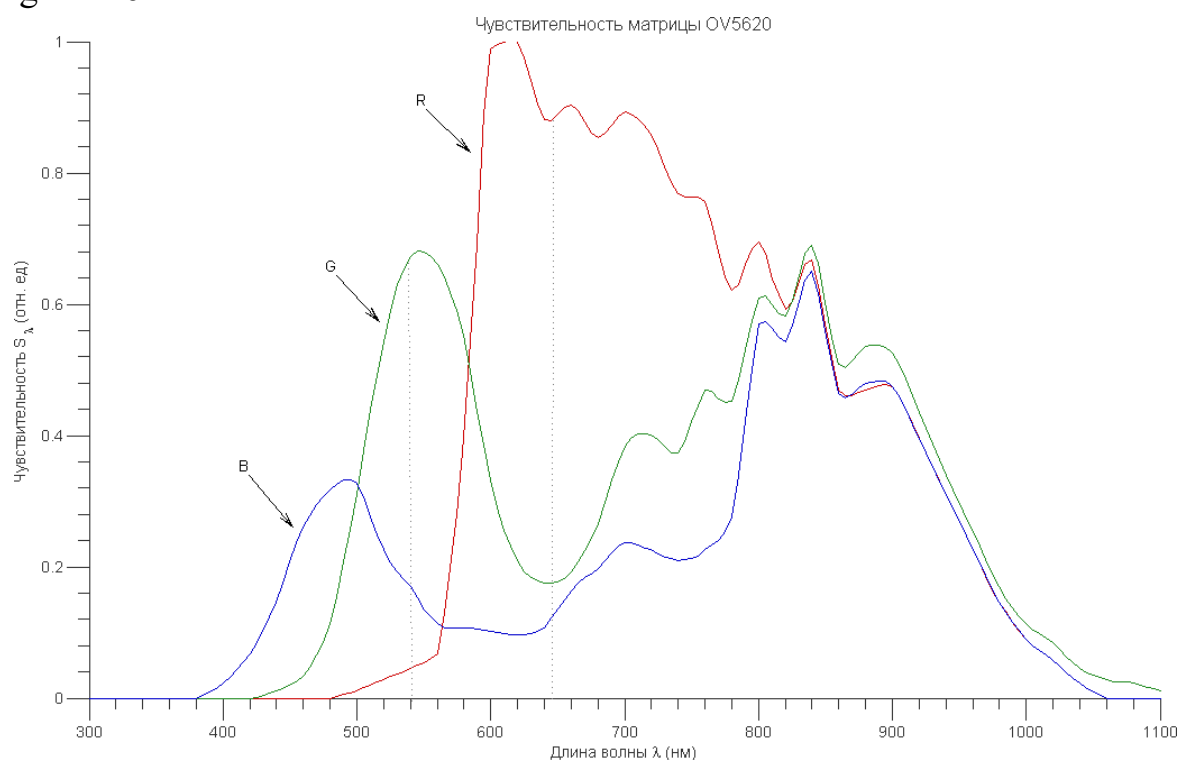


Figure 2.6 – Spectral sensitivity distribution of CMOS array OV5620 [9]

Practically Measurements superficial Sensitivity
Distributions sensor are performed in conditions uneven

distribution of the radiation flux in the cross-section of the light beam incident on the matrix. The irradiance of the matrix is due to the imperfection of the radiation indication of the source, as well as the heterogeneity of the parameters of the optical elements of the facility. Therefore, during the experiment, it is necessary to exclude the influence of irradiation unevenness over the site on the measurement result.

The method based on the use of the appearance of polarization sensitivity of the matrix pixels when it is oriented at a small angle to the optical axis makes it possible to take into account the influence of irradiation irregularity when determining the unevenness of the matrix sensitivity over the field.

The measurement experiment is performed at three values of the angle of incidence of radiation on the plane of the video camera matrix, which are 1° , 3° and 5° with the optical axis; at three values of typical lines (wavelengths) corresponding to the RGB filter on the matrix - 450 nm, 550 nm, 633 nm; at seven azimuth values of the polarizer transmission axis 0° , 15° , 30° , 45° , 60° , 75° , 90° degrees relative to the axis of the reference coordinate system, as well as without a polarizer in the optical scheme of the stand.

Video image processing algorithm

Registration of the irradiation distribution created by the radiation source and the optical system of the stand on the matrix is carried out using software developed in the LabVIEW environment, the main window of which is shown in Figure 2.7



Figure 2.7 – Main window of the program for conducting experimental studies

The Stokes2009-vi-main-hd program allows you to read the signal values from each pixel of the image, forms and saves numerical data arrays in the form of text files separately for the red, green and blue channels in the selected directory. The dimensions of the arrays correspond to the resolution of the matrix (2592x1944). The names of the saved text files correspond to the current position of the polarizer axes and are generated by pressing the corresponding buttons.

The files obtained as a result of the experiment should then be processed using a script written in Python or in the MATLAB software environment (at the discretion of the researcher). The program should read the files from the folder, process the values of the received signal for each pixel of the image, perform their statistical processing and visualization of the signal distribution on the surface of the matrix.

Method for measuring the heterogeneity of the photodetector sensitivity distribution over the field

1. At the beginning of the experiment, it is necessary to measure the dark noise of the chamber by covering it with a lightproof casing to account for the additive component of the geometric noise, subtracting the distribution of the "dark charge" at each measurement act.
2. Using a frame with a three-coordinate angular movement, set the video camera so that the angle of incidence of radiation on the plane of the matrix is 1° , the azimuth of the polarizer transmission axis should be set to 0° . In this position, it is necessary to remove the distribution of the signal over the field for three values of typical radiation wavelengths.
2. Next, turn the polarizer so that the azimuth value is 15° , and again take the signal values for three wavelengths.
3. Then we carry out further measurements with a change in the azimuth of the analyzer rotation with a step of 15° - each time for three values of typical wavelengths.
4. The final step is to measure the output signal in the absence of a polarizer – also for three wavelengths.
5. After that, we change the angle of rotation of the camera (3 and then 5 degrees) and take measurements that are similar to those described above.

A block diagram of the methodology for conducting an experimental study of the sensitivity of a photodetector based on CMOS arrays is presented in Figure 2.8.

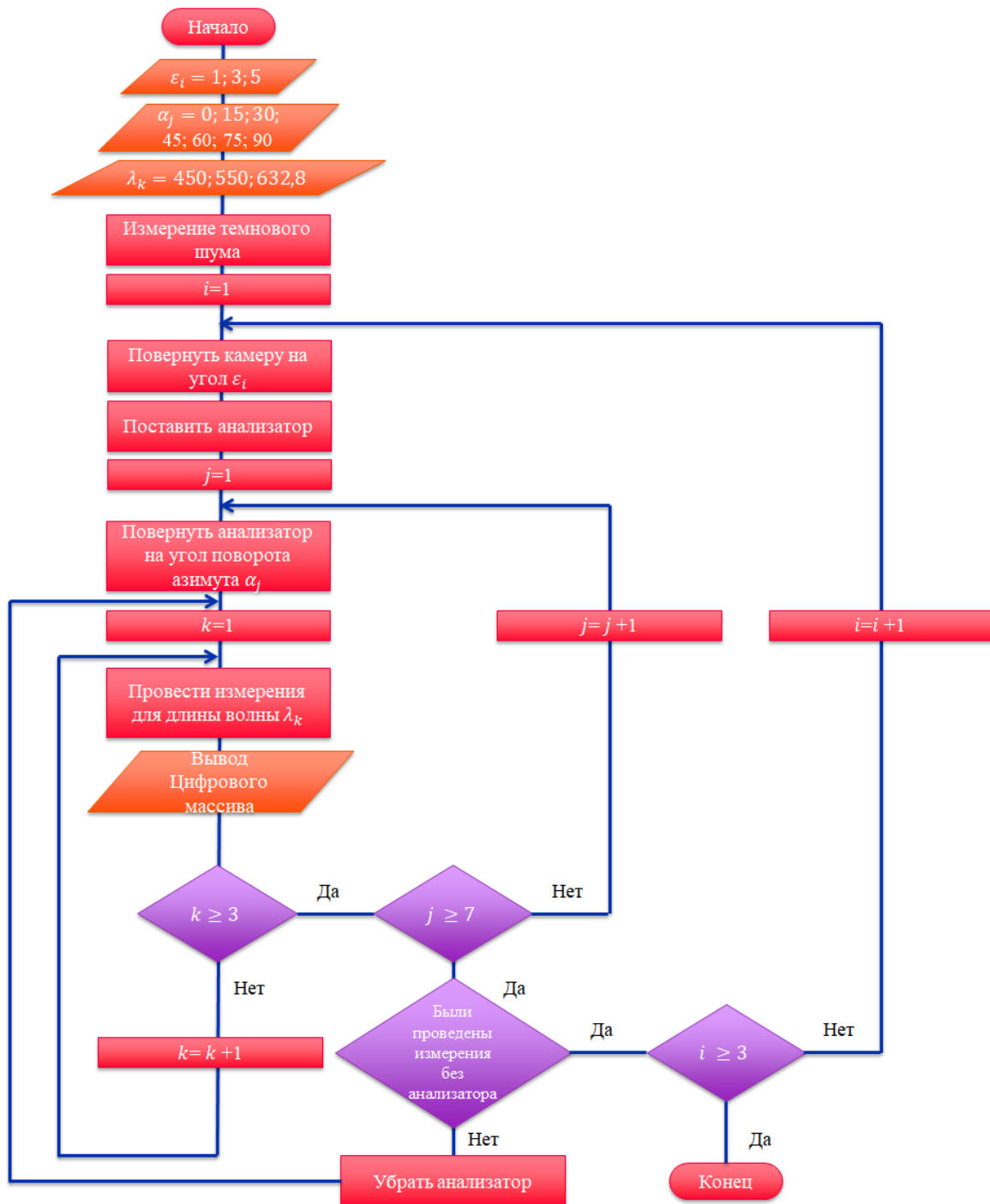


Figure 2.8 – Flowchart of the experiment methodology

Examples of presenting the results of the experiment

Measurement results for a wavelength of 450 nm with the participation of a polarizer. The received signals are shown in Figure 2.9. When the polarization changes, the signal value also changes due to the polarization sensitivity of the receiver. We find the value of this change by subtracting from the signal taken without an analyzer the signals corresponding to the positions of the polarizer azimuth from 0° to 90°.

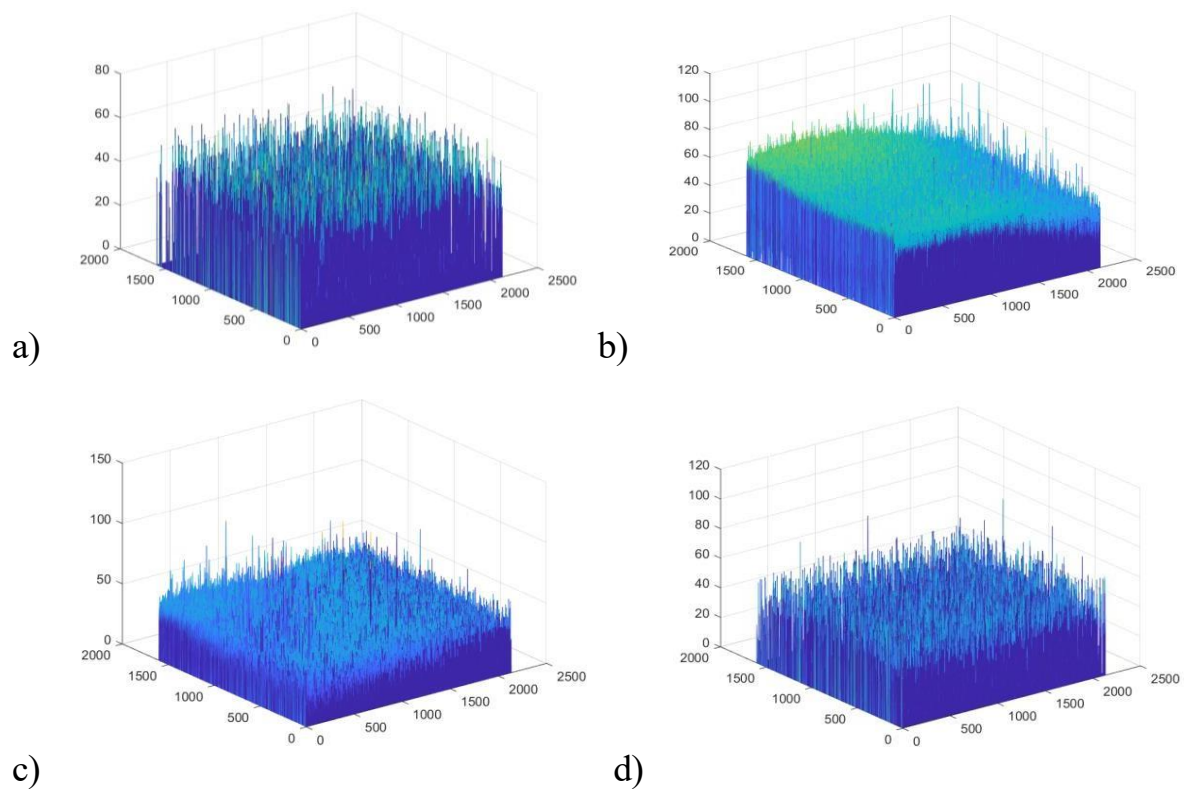
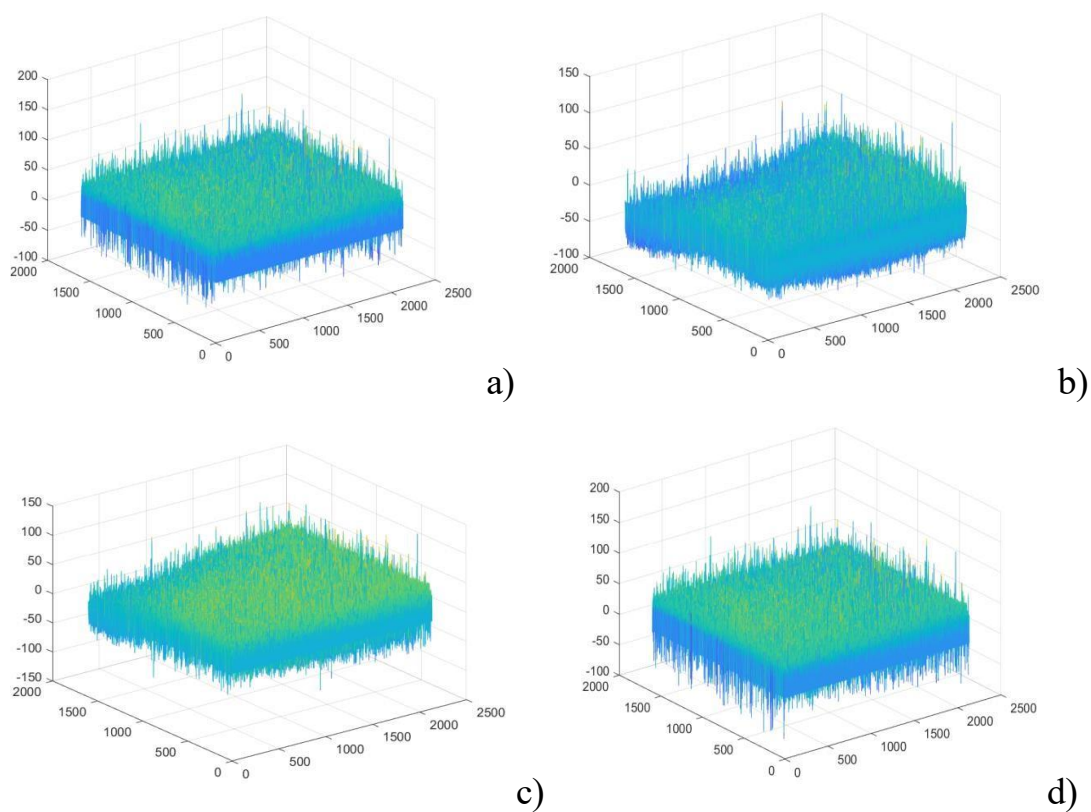


Figure 2.9 – Signals at the output of the matrix for a wavelength of 450 nm, at a rotation of 1° , at the positions of the polarizer: a) 0° , b) 15° , c) 30° , d) 45°

Examples Results per-pixel Subtraction Shown
Figures 2.10.



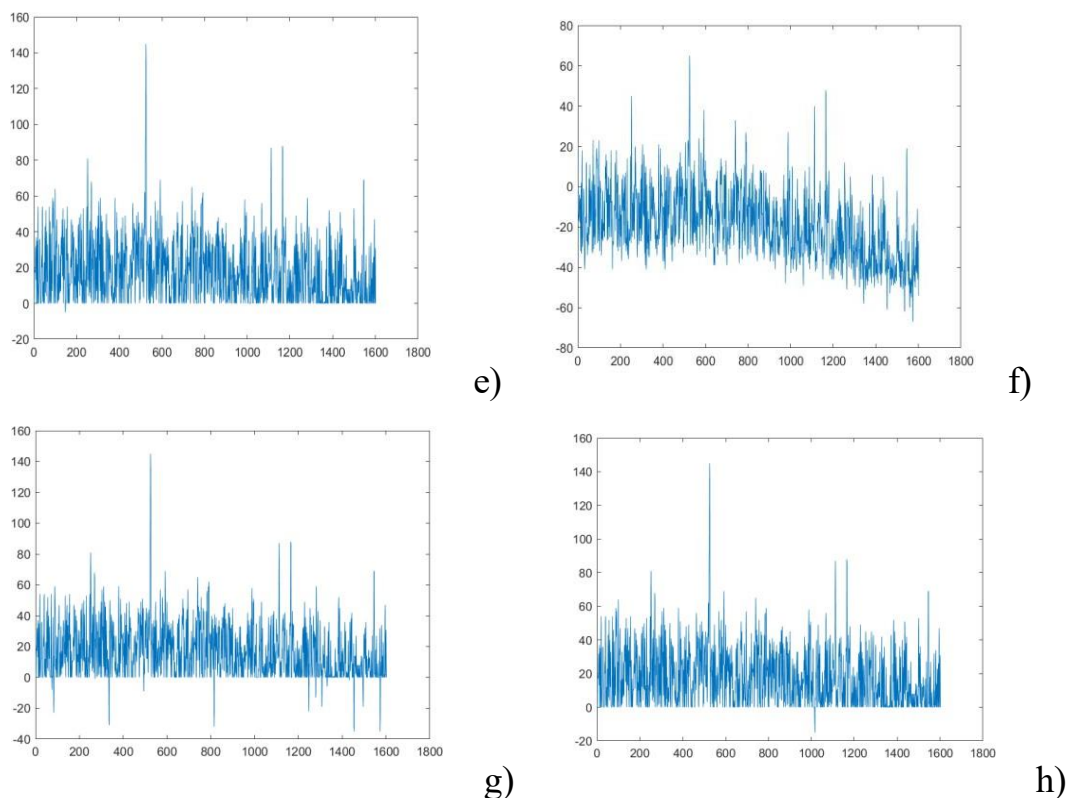


Figure 2.10 – Differences between the signals when the matrix is rotated by 1° without a polarizer, and when the analyzer is positioned a) 0° , b) 15° , c) 30° , d) 45° ; e), f), g) and h) – sample cross-sections of differences

Results measurements for Lengths Waves 550nm c
the participation of a polarizer. The received signals are
shown in Figure 2.11

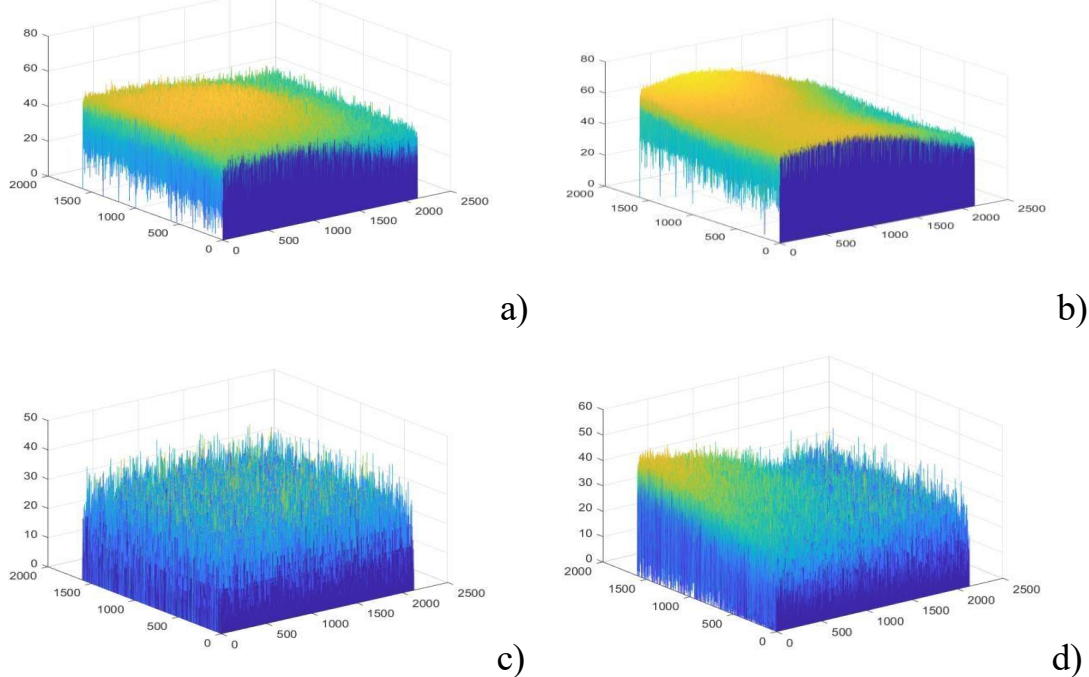


Figure 2.11 - Signals at the output of the matrix for a wavelength of 550 nm, at a rotation of 1° , at the positions of the polarizer: a) 0° , b) 15° , c) 30° , d) 45°

Similarly, when polarization changes, the signal value also changes due to the polarization sensitivity of the receiver. We find the value of this change by subtracting from the signal taken without a polarizer the signal with polarizer azimuth positions from 0° to 90° . The results are shown in Figures 2.12.

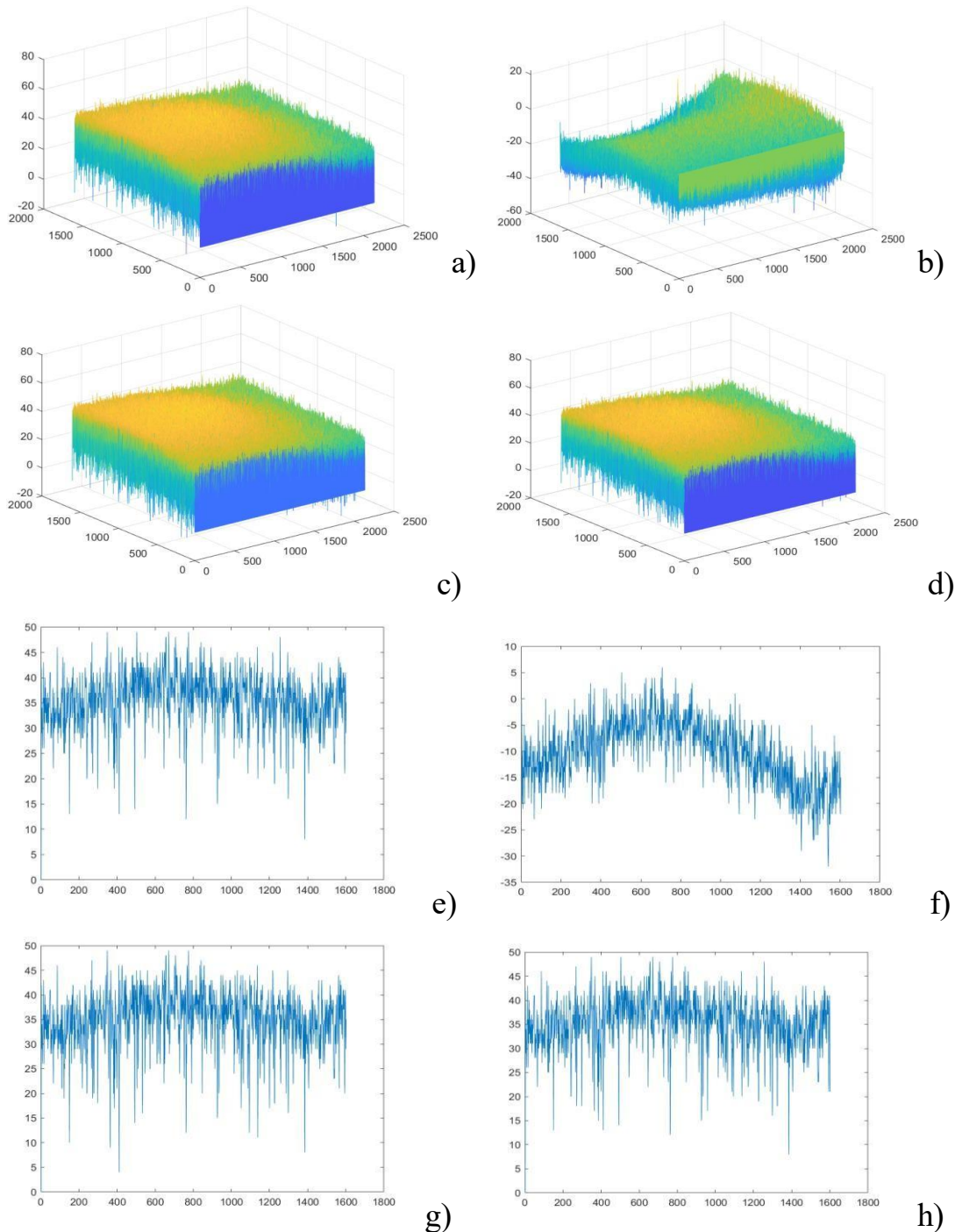


Figure 2.12 - Differences between the signals when the matrix is rotated by 1° without a polarizer, and when the analyzer is positioned a) 0° , b) 15° , c) 30° , d) 45° ; e), f), g) and h) – sample cross-sections of differences

Measurement results for a wavelength of 632.8 nm with the participation of an analyzer. The received signals are shown in Figure 2.13.

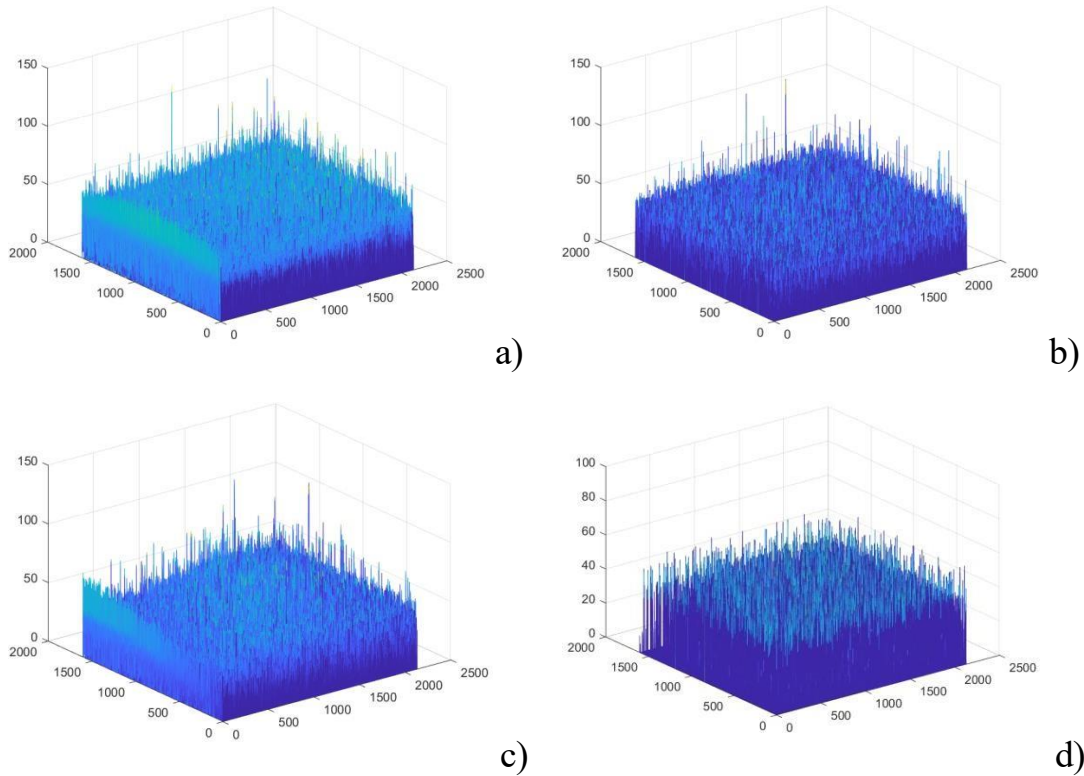
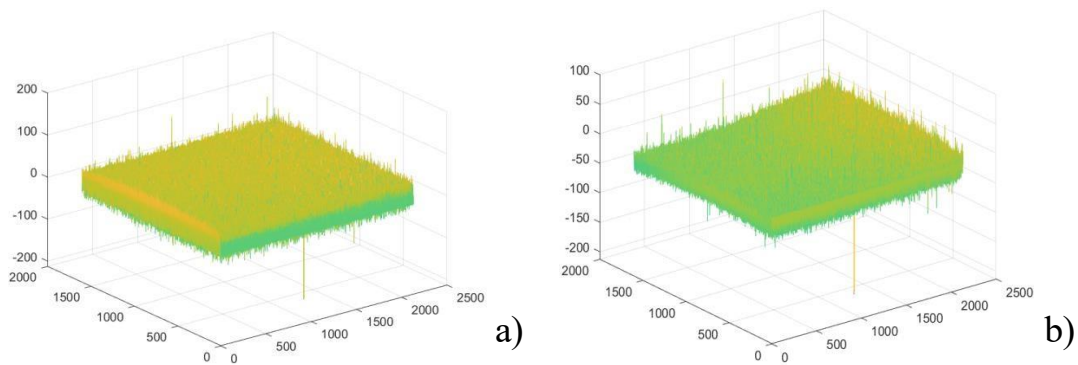


Figure 2.13 - Signals for a wavelength of 632.8 nm, with a 1° matrix rotation, at the polarizer positions: a) 0° , b) 15° , c) 30° , d) 45°

When polarization changes, the signal value also changes due to the polarization sensitivity of the receiver. We find the value of this change by subtracting from the signal taken without the analyzer and with the analyzer azimuth positions from 0° to 90° . The results are shown in Figures 2.14.



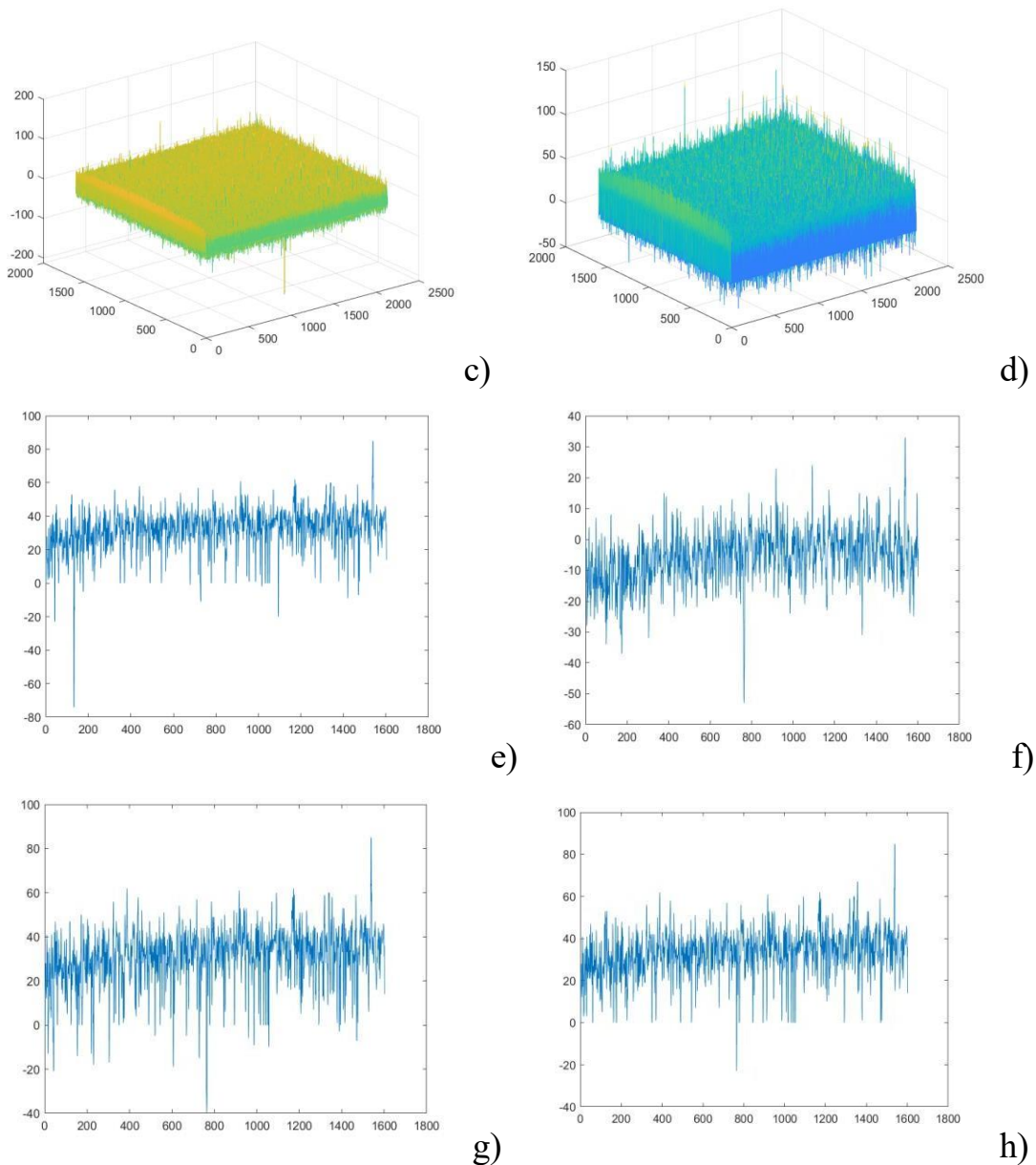


Figure 2.14 - Differences between the signals when the matrix is rotated by 1° without a polarizer, and when the analyzer is positioned a) 0° , b) 15° , c) 30° , d) 45° ; e), f), g) and h) – sample cross-sections of differences

Similar results should be obtained for measurements with different analyzer positions and camera rotation angles. An example of plotting the dependence of the signal difference on the rotation of the polarizer azimuth in the central region *N0* of the digital array at a radiation incidence angle of 1 degree is shown in Figure 2.15.

Similar distributions should be obtained at other angles of incidence (3 and 5 degrees) for the central region of the matrix, as well as for the other four (peripheral) regions of the array (*N1*, *N2*, *N3*, *N4*).

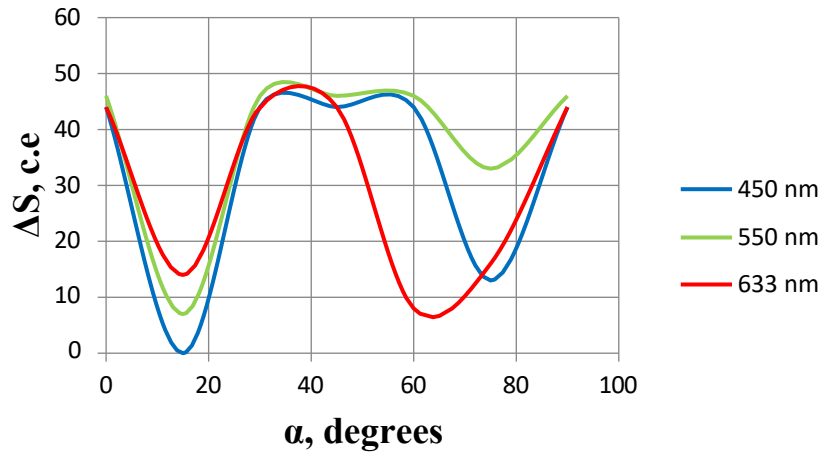


Figure 2.15 – Dependence of the signal difference on the rotation of the analyzer azimuth at the central point

An example of the dependence of the maximum signal difference on the angle of incidence of radiation in the central region *N0* of the digital array is shown in Figure 2.16. Similar distributions should be obtained at other angles of incidence of radiation for the central region of the matrix and for the other four peripheral regions of the array.

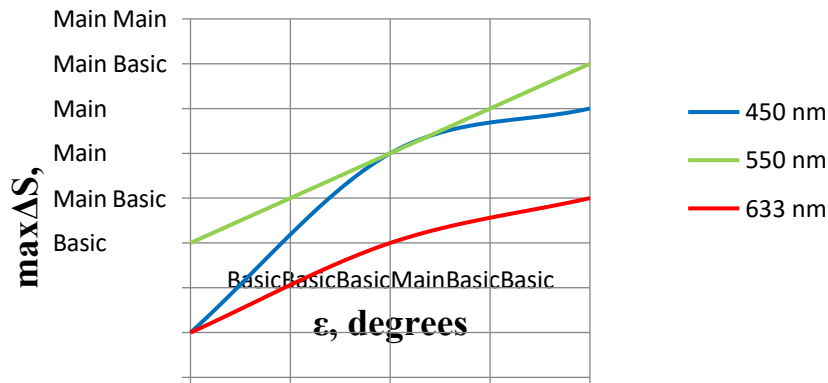


Figure 2.16 – Dependence of the maximum signal difference on the angle of incidence of radiation in the center of the matrix

If we compare the results for different series of the sensor rotation angle, we can see that when the matrix is rotated by 5 degrees, the polarization sensitivity is higher and the value of the signal difference is greater.

An example of constructing a summary table demonstrating the differences in the sensitivity of the MPI in the central and peripheral areas of the sensor surface is presented below:

Table 2.5 – Presentation of measurement results

E	max ΔS , emr														
	N0-N1			N0-N2			N0-N3			N0-N4			N1-N2		
	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm
1	7	0	10	9	19	15	13	0	2	6	14	12	2	19	5
3	4	2	10	13	18	17	10	0	0	9	15	13	9	16	7
5	4	3	3	14	19	11	10	0	7	10	14	1	10	16	14

E	max ΔS , emr														
	N1-N3			N1-N4			N2-N3			N2-N4			N3-N4		
	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm	450 nm	550 nm	633 nm
1	6	0	8	1	14	2	4	19	13	3	5	3	7	14	10
3	6	2	10	5	13	3	3	18	17	4	3	4	1	15	13
5	6	3	4	6	11	4	4	19	18	4	5	10	0	14	8

Procedure for performing laboratory work

The work is performed on a personal computer with a USB camera connected to it based on the CMOS sensor under study.

The work is designed for 4 hours and contains the following sections:

1. With the help of a teacher or laboratory assistant, power the monochromator and the illuminator, make sure that the radiation from the halogen lamp is directed to the input slit of the monochromator.
2. Calculate the normal slit width of the monochromator for a given wavelength using the formulas and set the required slit values based on the $S \gg S_0$ condition.
3. Turn on the laptop and wait for the operating system to boot. Connect the video camera under study to the USB port of the laptop.

On the monitor's desktop, find the shortcut to start the signal processing program in LabView. Create a personal directory on the C drive to record the files received after running the output processing program from the camcorder. In the future, save all files with the data processed in the course of work in your folder.

4. Use the method of experimental study of the non-uniformity of the sensitivity of the MPAI and carry out a set of measurements at different angles of rotation of the photodetector surface of the receiver relative to the optical axis of the system. Extract the required wavelength of radiation in manual mode of operation

monochromator using the stepper motor control buttons and indicators on the front of the spectrum instrument.

5. After each measurement act, save the text files corresponding to the signal distribution on the surface of the matrix in previously created folders in your personal directory. Signal values are recorded in Least Bit Units of the Analog-to-Digital Converter (ADC) (EMD), and the coordinates of the image elements are recorded in the numbers of the elements of the row or column.

Keep in mind that *the signal value should not exceed 250 emr*, otherwise the dynamic range of the ADC will be exceeded and the measurements will be incorrect! If the signal value exceeds 250 emr, then the accumulation time should be slightly reduced.

6. Process the measurement results and obtain three-dimensional diagrams and cross-sections similar to those given in the examples. Construct summary diagrams and tables that demonstrate the presence of non-uniformity in the sensitivity of the MPEI and its assessment for different areas of the matrix.

Contents of the report

1. Brief information about the noise of multi-element photodetectors.
2. Details About preparatory works and calculations c their interpretation for measurements.
3. Original and Processed Spatial distribution of the output signal at various parameters of the bench elements.
4. Summary charts and tables with results.
5. Brief conclusions on the work.

Control questions

1. What physical processes occur in the CMOS structure during the formation of the charge relief, what are the causes leading to the appearance of noise and distortion of the video signal?
2. What MPOI noises do you know? What is the peculiarity of structural noise?
3. What methods do you know of reducing the noise of MPOI or their algorithmic correction?
4. Explain how a monochromator works. Explain the purpose of each element in the optical design of a monochromator.
5. How is the polarization sensitivity of an isotropic photodetector calculated, as a result of which it appears and what does it depend on?

Practical lesson No3. Study of the video module for detecting abandoned objects

Objectives of the work:

1. To study the theoretical issues of the method of detecting abandoned objects by analyzing images in a video stream
2. To study the structure, interface, operating conditions and modifications of the video detector for searching and fixing various objects left in the field of view of the video camera as part of a television system based on Trassir software.
3. To study the functional features, the procedure for setting up and the main modes of operation of the detector of abandoned objects.
4. Gain practical skills in setting up equipment, working with the module for detecting abandoned objects and determining its main characteristics.

Brief theoretical information

The search and timely detection of abandoned objects is one of the key tasks faced by analytical video systems. Situational control based on the detection of abandoned or abandoned objects of various kinds is implemented to ensure the anti-terrorist security of facilities characterized by mass gatherings of people (subway, railway stations, airports, other transport infrastructure facilities, banks, museums, shopping and entertainment complexes, markets, sports facilities, etc.). [24]. The video module for the detection of abandoned objects is designed for use in video surveillance systems for the purpose of automatic detection of abandoned or disappeared objects, objects, things and other stationary changes in the scene that occurred in the observation area in the field of view of the video camera and remain motionless for a given period of time.

In addition, such a detector makes it possible to register foreign objects (dropped loads, thrown objects) in the lane, which are always a potential cause of dangerous situations on the roads, since not all drivers react to obstacles in time and correctly [25].

When detecting abandoned objects, the most common model is encoded in which the object is considered ownerless if it has been static for a certain time and there were no people near it. . present, there are two classes of algorithms that allow solving the problem of detecting abandoned objects:

- algorithms based on the search for foreground objects and the performance of a series of operations (including the use of neural network classifiers) to process event candidates, on the basis of which the system notifies about an abandoned or dropped object;
- algorithms based on tracking moving objects, which are a logical development of background selection algorithms and implement them at the first stages of work.

Method based on foreground object search algorithms

If a standard video detector shows any changes in the frame compared to the previous one, then the foreground detector provides static information, showing only changes relative to the background. Such changes can be caused by any stationary object that has changed any part of the background of the frame by its appearance or disappearance. For example, a bag placed on the floor, or vice versa, carried away. A car that has occupied a certain place in the parking lot, or a car stolen from this place.

The foreground refers to all the moving objects in the frame. The pixels corresponding to the stationary objects form the background. This method uses two background models: short-term (rapidly changing) and long-term (slowly changing), each characterized by the speed and time of the update.

A short-term background model has a negligible update time, so changes in the current frame compared to the previous ones have time to be fixed in the changing background. If a new object appears in the frame in motion, it will not become a background. If the object has stopped and become stationary (which is characteristic of the so-called "abandoned objects"), it will merge with the stationary background of the frame. Thus, the short-term background allows you to determine that there was movement in the frame (there was a moving object), and now there is no movement (the object has become static and merged with the background).

With all the simplicity and logic of the short-term model, it cannot be sufficient for detection, since a stationary abandoned object "disappears" very quickly - it merges with the background, and it is impossible to record the time of its "rest". Therefore, the foreground algorithm uses both background models at the same time. The long-term background model changes much more slowly, new objects, getting into it, remain in the foreground for some time and only after a long time become the background. This allows you to detect the abandoned object more confidently, to assess that it got into the scene some time ago, and was not the original background.

The system operator can set the time after which the item will be considered abandoned. Having received this data, the system will calculate a coefficient that will adjust the time of updating the long-term background. The logic of the algorithm is shown in Figure 3.1.

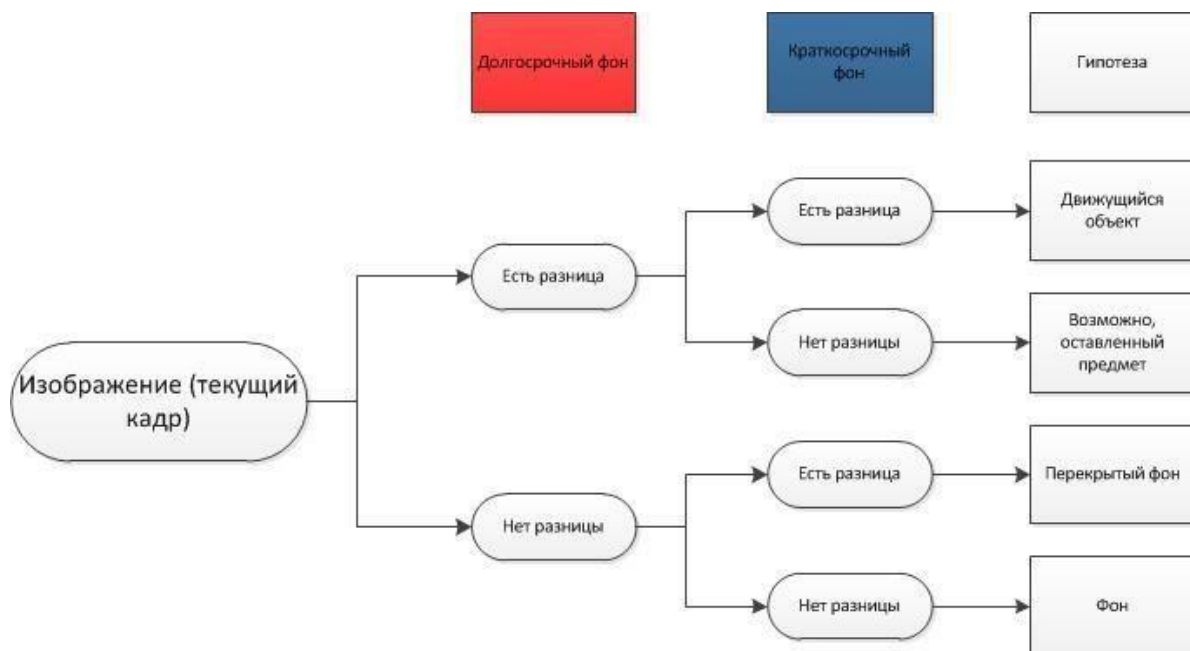


Figure 3.1 – Logic of the detector of abandoned objects using the method of searching for foreground objects [24]

Each pixel of the current frame is compared with the corresponding pixels of the long-term and short-term background. The hypothesis is built depending on the result of the comparison.

Method based on tracking algorithms

Tracking algorithms are aimed at detecting both the abandoned object and the person who left this object.

The video system records the division of one moving object into two: static and moving, then follows the static object.

In the tracking approach, the first step is also to isolate the background. Next, the system builds the trajectories of all moving objects in the frame, and then fixes the "division" of the moving object into two, one of which continues to move, and the other remains static. The detection procedure is based on the analysis of the speed, direction of movement of objects, and their color characteristics, which are used to match the object and the person when they are "separated" into two objects (Fig. 3.2).



Figure 3.2 - Detection of an abandoned object and its owner [24]

Next, the probability of the object's transition from one point of the previous frame to another point of the current frame is calculated for the correct assignment of the trajectory of movement when several objects are moving simultaneously in the frame. All these calculations require a lot of computing power.

A comparative analysis of the methods (Table 3.1) shows that for both algorithms, false alarms are possible when a person is delayed in the frame for a time equal to the time after which the object will be considered abandoned. The difficulty may lie in the inability to distinguish a person from a potentially interesting object (for example, if a person takes a pose in which it is difficult for the program to identify him, for example, sits down). The problem is solved by combining the detector with a neural network classifier capable of recognizing categories of objects and distinguishing a person in any position from other objects.

At the same time, the most stable and less resource-intensive algorithm is the one that uses **the selection of foreground objects**, but it is unstable in conditions of high traffic intensity and when shooting conditions change (for example, changes in lighting).

Table 3.1 - Comparison of algorithms for the method of searching for abandoned objects

Features algorithms	Object search algorithms foreground	Object tracking algorithms
Strengths of algorithms	A high level of detection of the abandoned object with the correct setting of the true background - when the background hits the frame completely for a while, without overlapping crowd	In addition to the object, the person who left it is detected; obtaining data on the movements of this person in the field of view of the camera, as well as during inter-camera tracking ("interception") to search for him
Difficult situations in which it is possible to miss abandoned items	Work in a crowd and in conditions of partial change of illumination - the impossibility of correctly determining the background	High intensity of traffic, overlapping moving objects, temporary loss of the object from the camera's field of view - difficulties in distinguishing an individual moving object
False Actuation	When a person is delayed in the frame, it is solved by combining with classifier	
Connection with a person, who left the item	Absent	Present
Complexity of processing processes and Resource intensity	Medium	High

The stability of the algorithm is improved by using the motion detector, which allows you to pre-create masks from frames for all moving objects in the frame. Further, the background is updated only in those areas of the frame where there are no moving objects; in those areas of the frame where there are masks of moving objects, the update does not occur.

Reducing the number of false alarms is also achieved by additional checking of the object for static, which makes it possible to exclude temporarily static objects that are not of interest to the operator. To check the static, the frame of the potentially abandoned object is selected and its position is remembered. Further, when a new frame arrives, the frame of the static object is also selected

object, its coordinates are compared with the values of the saved coordinates. If a positive result is obtained after the comparison (that is, the frames are approximately the same), then the check is repeated several more times (the number of checks depends on the required time to find the abandoned object). If a negative result is obtained after the comparison (that is, the frames do not match), the check count is reset to zero, and the saved frame is deleted.

A successful modification of the classical method of selecting the background and searching for foreground objects in brightness images is **the method by sequence of long-range images**.

Analysis of long-range images is the basis of algorithms that make it possible to detect abandoned objects regardless of the presence of shadows, contrast level and changes in illumination. Each element of such an image contains information about the distance from the sensor to the point of the object in the scene [26,27].

The object left behind is considered as a connected component of the range image $I_t(x, y)$, which is not a background, its area lies in the interval (S_{min}, S_{max}) of pixels, its coordinates do not change in k consecutive frames [26].

The structure of the marking point image element is as follows:

$$Kt(x, y) = \begin{cases} 1, & \text{belongs to the abandoned object} \\ 0, & \text{belongs to the background} \\ -1, & \text{belongs to a moving object} \end{cases},$$

where t is the frame number. The construction of the background consists in accumulating the pixels of the image with the highest distance value, taking into account the noise.

The background value of $Bg(x, y)$ is accumulated over a limited number of frames. The result of background selection is saved as a binary foreground mask or background:

$${}_t O(x, y) = \begin{cases} 1 & \text{foreground,} \\ 0 & \text{background.} \end{cases},$$

If there is no background image, the output is the first image marked as background $Bg(x, y) = I_1(x, y)$.

To prevent filling the background with points belonging to the object, the proximity of the values of the point of the current image and non-zero points in the vicinity of an unknown background point is used:

$$|I_t(x, y) - Bg(x + a, y + b)| < \theta,$$

where B_g is the first image, $a, b \in [1; -1]$, and θ is the given threshold.

If this condition is met for at least one of the points, then it is embedded in the background $B_g(x, y) = I_t(x, y)$, $O_t(x, y) = 0$, otherwise this point is the foreground $O_t(x, y) = 1$.

Making a decision whether the object found on the image left is performed on the basis of two strategies that differ in the method of counting frames: for static and dynamic scenes.

For scenes with few movements, a quick strategy is used. A frame counter is entered for each element

$$N_t(x, y) = \begin{cases} N_t(x, y) + 1 & \text{if } O_t(x, y) \neq 0, \\ 0, & \text{otherwise} \end{cases}$$

which is incremented if the element's value belongs to the foreground, it is reset in the opposite case.

A precise recognition strategy is used to work in the flow of moving objects. The frame counter determines l frames ($l \gg k$) from the history in which the pixels of the abandoned object from the previous frame were marked:

$$N_t(x, y) = \sum_{i=t-l}^{t-1} \begin{cases} 1 & \text{if } |I_t(x, y) - I_i(x, y)| < \theta \text{ and } O_t(x, y) O_i(x, y) \neq 0, \\ 0, & \text{otherwise.} \end{cases}$$

If the difference in the values of two pixels that belong to the foreground is less than the specified threshold θ , then we assume that the pixel belongs to the same object at times t and i .

After the frame counter exceeds the specified threshold k , the image element is considered to belong to the abandoned object:

$$K_t(x, y) = \begin{cases} 1, & N_t(x, y) > k, \\ 0, & \text{otherwise.} \end{cases}$$

where $K_t(x, y)$ is the image element.

Next, the areas of the related components $K_t(x, y)$ are evaluated and a decision is made whether the object is an abandoned object or a moving object.

Abandoned Object Detectors in Trassir Software

TRASSIR Object Left Detector is an intelligent module for detecting abandoned objects (abandoned object detector) in the field of view of a video camera. The parameters of the expected object of detection are configured. The detection results can be seen in the log

(instructions on how to create working windows in Trassir using templates for monitoring the event log can be found in the manual [28], in the description of Laboratory Work No2).

The module allows you to quickly identify abandoned and forgotten items in a facility where video surveillance is installed. Trassir software has three built-in detectors for abandoned items: Simple, Improved and Alternative. Functional features and the procedure for setting them differ depending on the selected detector [29].

Simple Abandoned Object Detector:

- detects objects of a certain size;
- uses the entire survey area for analysis;
- allows you to determine the zone of ignorance;
- does not require a separate license.

Improved Abandoned Item Detector:

- detects objects of various sizes;
- Uses specific survey areas for analysis.
- has advanced detection settings;
- uses two detection algorithms;
- works on a schedule;
- Licensed on a channel-by-channel basis.

Alternative (neural network) detector of abandoned objects:

- detects objects of various sizes;
- uses the entire survey area for analysis;
- allows you to determine the zone of ignorance;
- has advanced detection settings;
- uses two detection methods;
- learns in the process of work;
- requires IntelliVision module activation and is licensed on a channel-by-channel basis.

As a rule, all detectors detect abandoned objects in the entire image area. It is possible to reduce the search area by specifying the ignore zones or zones of specific sizes and locations in the frame.

Composition of the laboratory unit

The work is carried out on the basis of a universal laboratory complex of network video systems (ULK SVS), which contains

video equipment and Trassir software manufactured by DSSL. The ULC includes network television cameras, video servers, workstations based on personal computers, as well as passive network equipment.

The schematic diagram of the SHS LCM is shown in Figure 3.3. Two groups of IP cameras 1 and 3 are located on the same network with computers 5 and 6 on which the Trassir software server parts are installed, and with groups of computers 7 and 8 on which the Trassir software client part is installed, using switches 2 and 4.

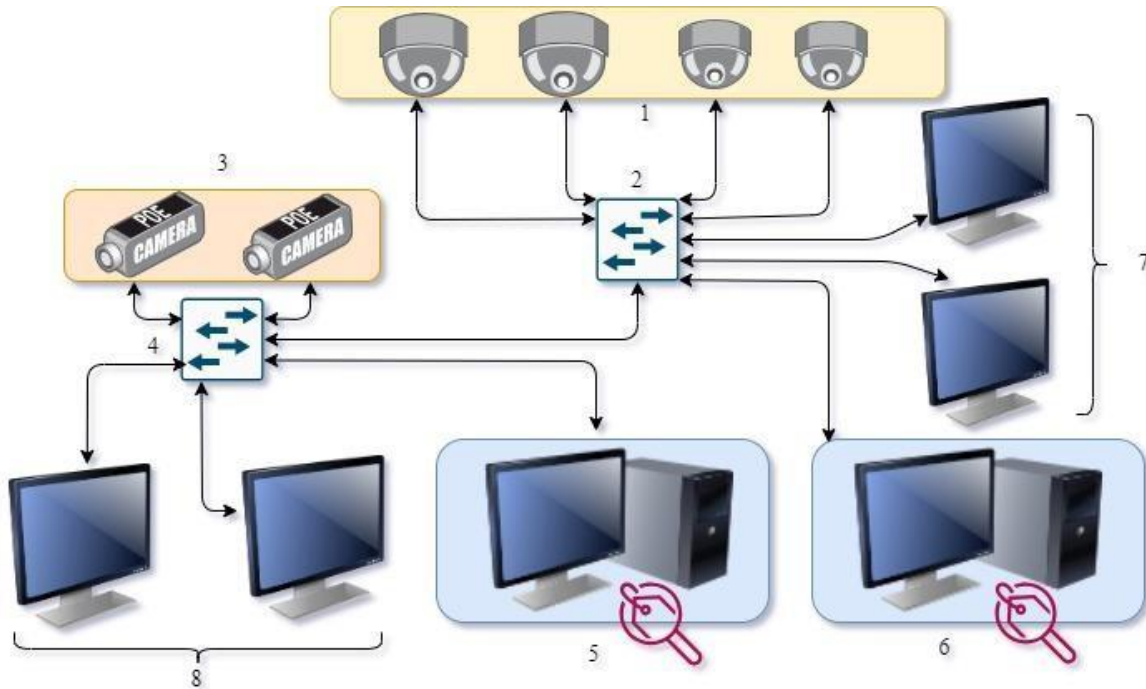


Figure 3.3 – Schematic diagram of the ULK SHS

The Trassir system potentially allows you to form a tree-like hierarchical structure of video surveillance. The architecture of the system is open and involves the ability to connect several servers, additional cameras and the required number of workstations [28].

The system consists of six network television cameras manufactured by DSSL, of which four are dome cameras (PTZ and fixed) and two cameras in a standard internal housing. The parameters and characteristics of the cameras are shown in Table 3.2.

The computers that are part of the ULC SHS are not specialized and are used for other purposes of the training laboratory. Therefore, two network computers are installed in the computers of the ULC

cards for correct operation in the university Internet network and in the local network of the SHS. Computers and cameras as part of the ULK VSB have fixed IP addresses.

Table 3.2 – Parameters and characteristics of video cameras

Type and parameters of IP cameras	PTZ Dome Cameras AC-D5024	AC-D4111IR1 Small Dome Cameras	Interior Chamber AC-D1020	Interior Chamber AC-D1050
Camera Appearance				
Format, Matrix type	1/2.8" CMOS 2 MP	1/2.7" CMOS 2 MP	1/2.8" 2.1 MP Sony EXMOR	1/2.5" CMOS 5 MP
Sensitivity	col. 0.05Lux (F1.6) B&W 0.005Lux (F1.6)	0.005Lux (F1.8) 0 Lux - IR on	Tsv. 0.03 Lux at F1.2 CB 0.003Lux at F1.2	
Resolution	2MP FullHD (1920x1080) 1 MP HD720p (1280x720)	2 MP FullHD (1920x1080)	2.1 MP FullHD (1920x1080)	5MP (2592x1944) 3MP (2032x1536) 2 MP FullHD (1920x1080)
Write Speed	2MP @ 25 fps 1MP @ 50 fps	2 MP @ 25 fps 1 MP @ 50 fps	25 fps	5 MP @ 15 fps 3 MP @ 20 fps FullHD @ 25 fps
Day/Night Mode	Mechanical IR Filter	Mechanical IR filter IR illumination up to 15 m	Mechanical IR Filter	Mechanical IR Filter
Dynamic range	D-WDR (120 dB)	D-WDR	D-WDR	Real WDR (120 dB)
Image Correction	3DNR, BLC, HLC, Defog	3DNR, BLC, Defog	2DNR, BLC	2DNR, BLC
Lens	zoom lens 5.1-61.2 mm (x12 optical zoom, x16 digit zoom), ARD, autofocus	3.6 mm (with 3-axis mounting)	C/CS with ARD support	C/CS with ARD support
Anxiety	2/1	-	1/1	1/1
Local video archive	microSD up to 32 GB	microSD up to 128 GB	-	microSD up to 32 GB
Nutrition	24B AC / PoE+ (802.3 at)	12V DC/PoE (802.3 af)	12V DC/PoE (802.3 af)	12V DC / PoE (802.2 af)
Consumption	up to 12 W	up to 3 W	up to 3 W	up to 3.6 W

IP address	<i>192.168.1.188</i> <i>192.168.1.193</i>	<i>192.168.1.189</i> <i>192.168.1.192</i>	<i>192.168.1.190</i>	<i>192.168.1.191</i>
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Access to the cameras for setting parameters is carried out through a browser when referring to the camera as a web server using its IP address using the HTTP protocol. When operating cameras under the control of Trassir, the RTSP protocol is used.

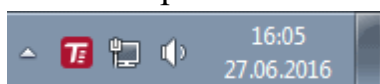
The Trassir software includes a server and a client part. You can log in locally on the Trassir Server or remotely through another server, Trassir Client or WebView. To run the Trassir Server application, you need a Guardant USB key connected to the server and a license file. A USB key and license are not required to run the client application.

Trassir software can be run in two modes:

- **In normal mode** , launch the "Trassir 4 Server/Client" shortcut created during installation in the Start menu (the watchdog-vc120.exe file from the TRASSIR root folder will be launched). In this case, the server status will be monitored by a special module - *Watchdog*.

- **In "no crash restart" mode**, run the "Trassir 4 Server/Client (no crash restart)" shortcut created during installation in the Start menu (the t1server-vc120.exe/t1client-vc120.exe file from the TRASSIR root folder will be launched).

A sign of a successful launch is the display of the main control panel icon at the top of the screen and the presence of an icon in the taskbar:



For the system to work, all equipment must be in one local subnet. The selected and configured subnet has an address range of *192.168.1.1-192.168.1.254* (corresponds to the mask *255.255.255.0*).

I. Setting up the Trassir backend:

a. To start the server, you need to open the main control panel by clicking the main control panel launch icon , which is located in the center of the upper border of the screen;

b. In the window that opens (Fig. 3.4), select the *Admin user*, the password is empty.

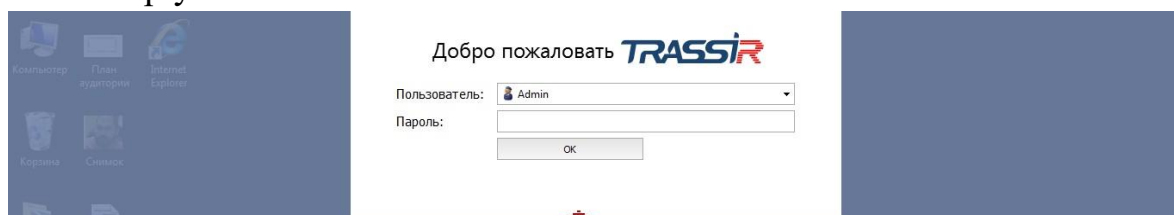


Figure 3.4 – Trassir server startup window

c. if the authorization is successful, the *Templates window* will open. To start setting up the server, click on the red arrow on the upper border of the screen again and click on the *Settings button in the Health Indicators* panel that starts (Fig. 3.5).

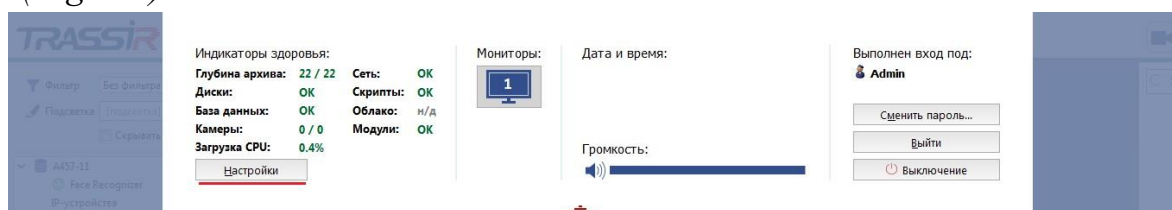


Figure 3.5 – Trassir Server Health Dashboard window

d. click the arrow next to the server name to expand the project tree (Fig. 3.6);



Figure 3.6 – Activating the project tree

e. After Performance previous Item Opens Window Settings (Figure 3.7).

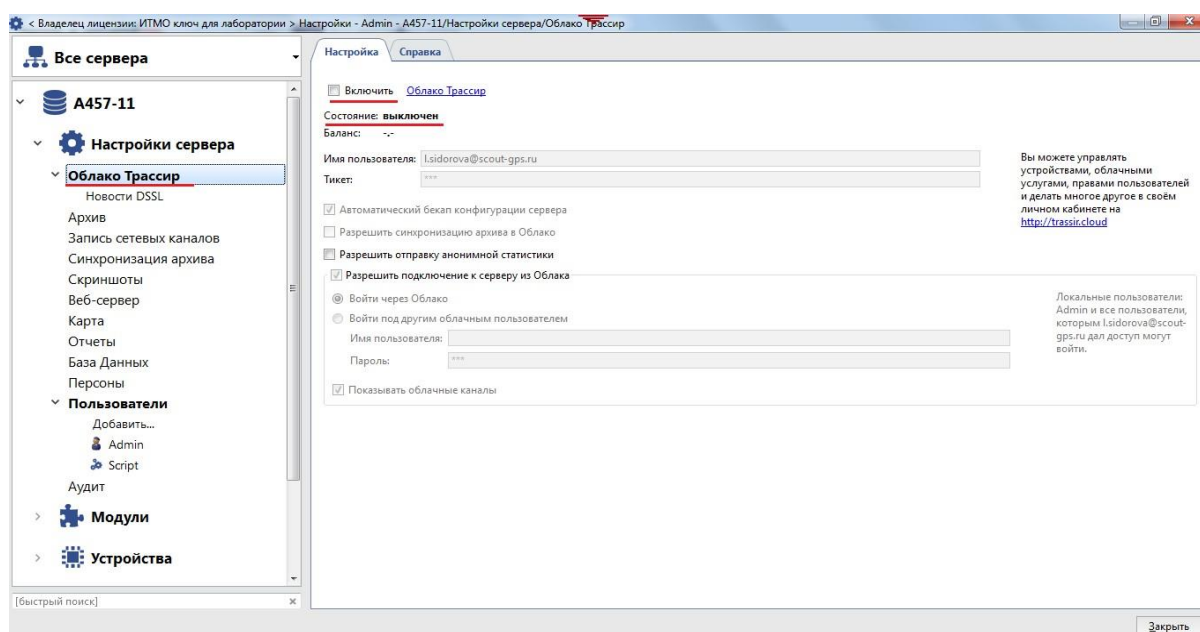


Figure 3.7 – Trassir Cloud Shutdown Process

f. *In this configuration of the system, Trassir Cloud is NOT USED, it is necessary to disable it to prevent errors.* To do this, in the *Trassir Cloud* tab, uncheck the Enable option.

II. Adding and configuring IP cameras:

a. in the *Server Settings* window, open the *Devices* drop-down list and select *IP devices* (Fig. 3.8). If there is power on IP cameras and their proper wired connection, the IP addresses of the cameras will be displayed in the field of available IP devices.

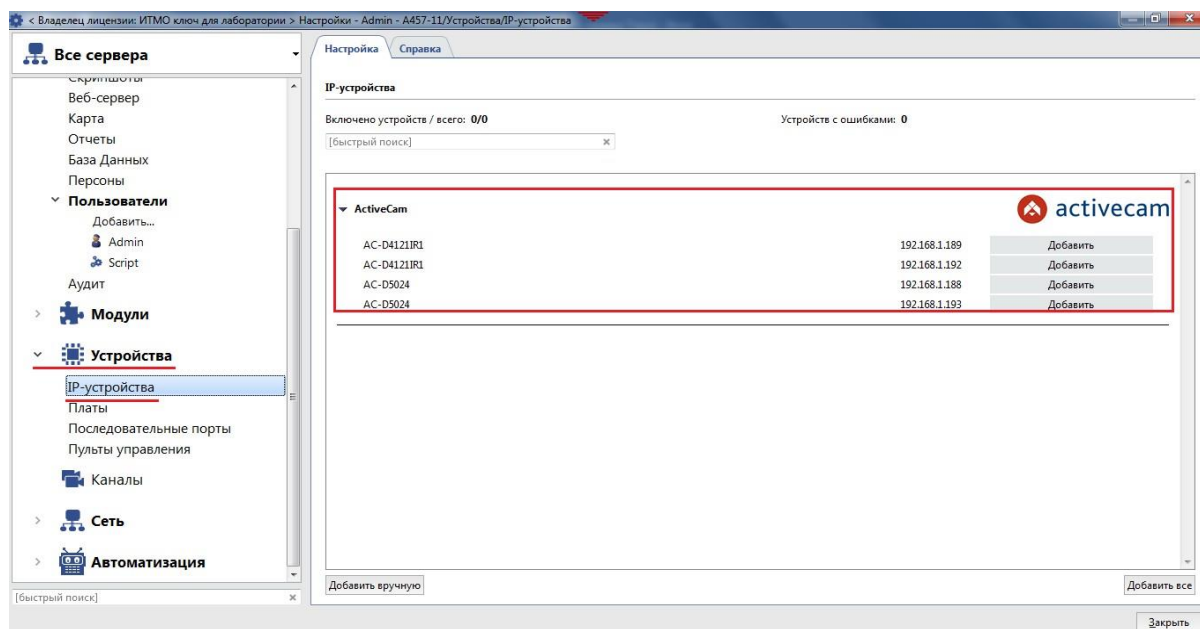


Figure 3.8 – Process of connecting IP cameras to the Trassir server

b. click the *Add* button next to the cameras that you plan to connect to the server. Upon successful connection, the camera will appear in the drop-down list of *IP devices*, the *Camera model* inscription will turn green, the name of the *Add* button will change to *Add*, the number of enabled devices will change to *1/1*, the number of devices with errors should be equal to *0* (Fig. 3.9).

c. configure each of the added cameras by clicking on the IP camera in the drop-down list of *IP devices*. Change the *Device Name (channel)* to a logically understandable one.

d. click on *Channel Setup* and set an identical *Channel Name*, which should display the camera function in the system.

III. Creating users with specific rights

The user (client) settings must have the server permission to use analytics over the network. To do this, the following sequence of actions on the server is recommended:

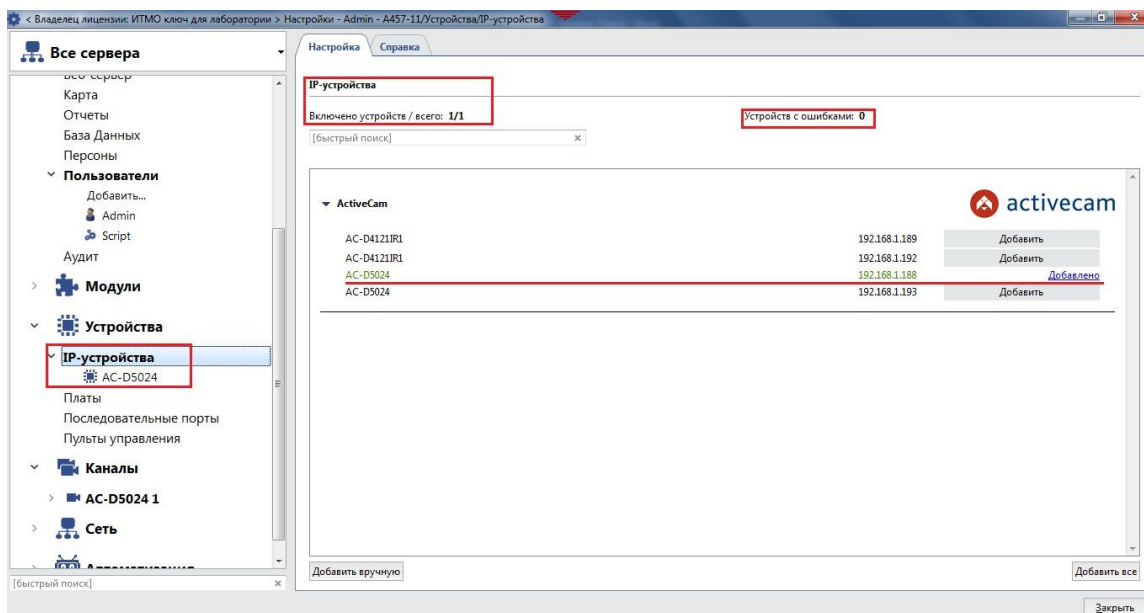


Figure 3.9 – Result of connecting an IP camera to a Trassir server

a. In the *Server Settings* window, go to the *Users menu*, where select the user (client) to whom you want to allow analytics over the network (Fig. 3.10);

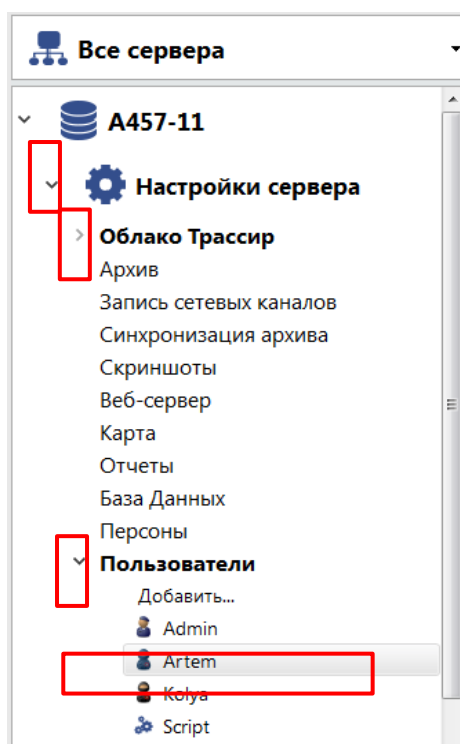


Figure 3.10 – Example of Artem user selection

b. check the box next to the "Allow analytics over the network" item in the working window (Fig. 3.11).

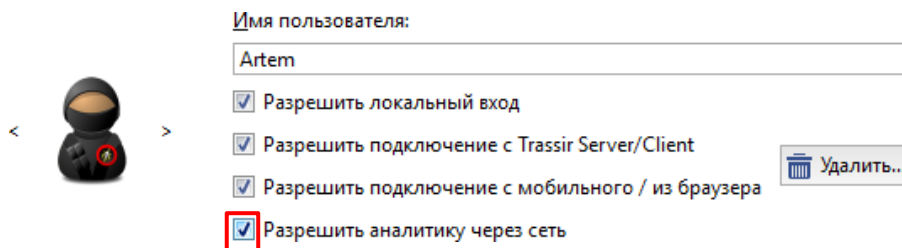


Figure 3.11 – Delegation of authority to a user

Procedure for performing work

The work is designed for 4 hours and includes the following sections:

- switching on the laboratory unit and preparing it for operation;
- connection and configuration of the camera, which will be used as part of the modules for detecting abandoned objects;
- mastering the methodology for configuring Left Object detection modules:
 - work with a simple detector;
 - work with an improved detector;
- Experimental study of the functionality and algorithms of the module of abandoned objects;
- Shutdown of the laboratory unit.

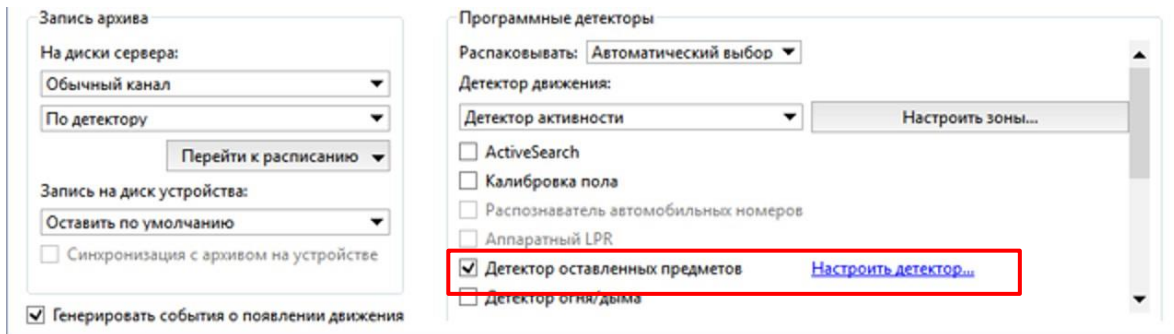
I. The laboratory unit is switched on and prepared for operation in the following sequence:

- supply power to video cameras;
- Turn on the computer using the button on its front wall.
- After turning on the computer, Windows will automatically start and the pre-installed Trassir Server software will automatically start.
- if there is a hierarchical structure of the Trassir system, it is necessary to create Users for computers with the Client status on PC Server and delegate to them the rights to work with analytics via the network (see the methodology within the description of the ULC SHS)

II. Connection and configuration of the camera that will be used for the operation of the Abandoned Items module.

The procedure for connecting and configuring IP cameras is carried out in accordance with the methodology set out in the description of the ULK SHS based on Trassir.

III. To connect and configure any of the built-in detectors, set the **Detector of abandoned objects flag** in the Channel Settings and click on the *Configure detector link* (Fig. 3.12).



with General settings for detectors of abandoned objects.

In the Settings window that opens (Fig. 3.13), on the General tab, select the detector operation algorithm from the **Detector type – Simple [29]** drop-down menu.

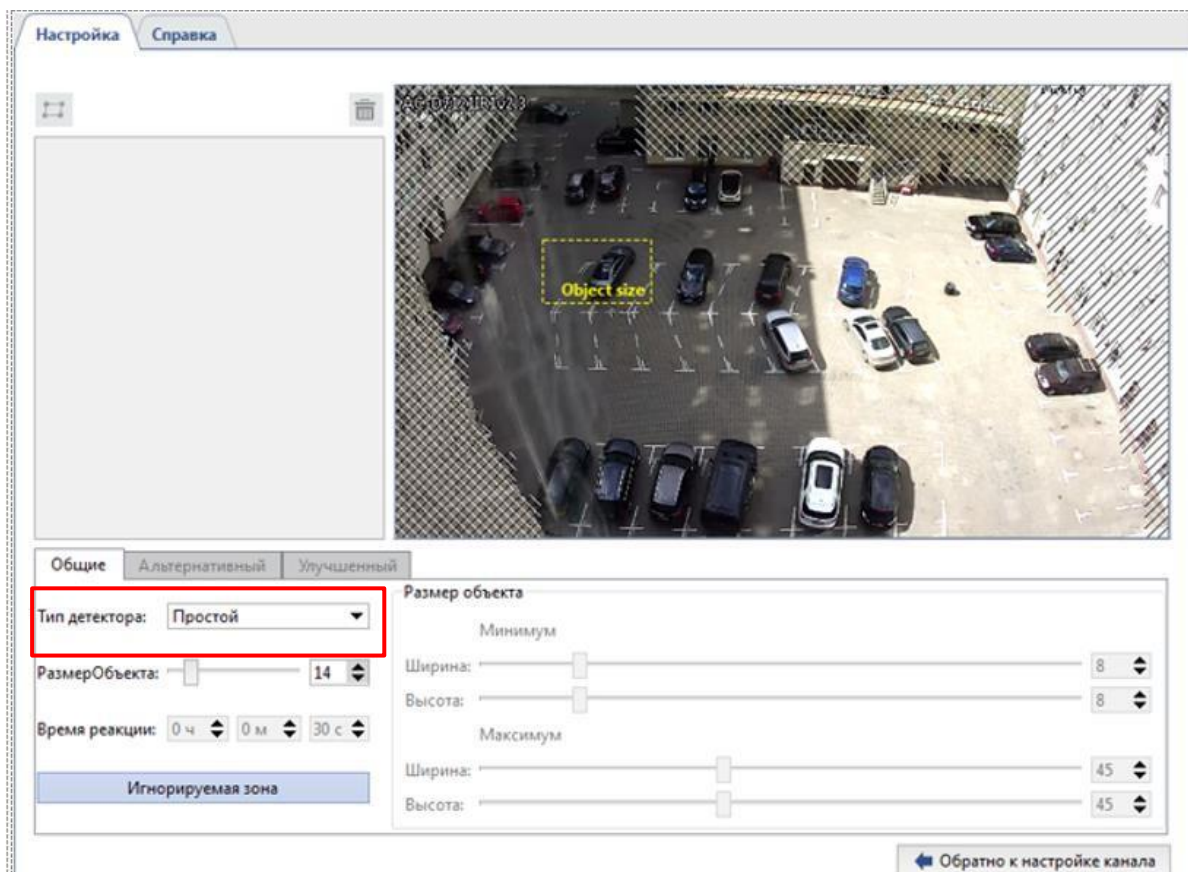


Figure 3.13 – Settings window of the simple detector of abandoned objects

By default, the detector monitors the appearance of abandoned objects in the entire image area. If necessary, you can reduce the area controlled by the detector. To do this, in the Channels tab – "Camera name" – Abandoned objects, select the ignored zones: click the **Ignored zone** button and, holding down the right mouse button, select those areas of the image that the detector should ignore.

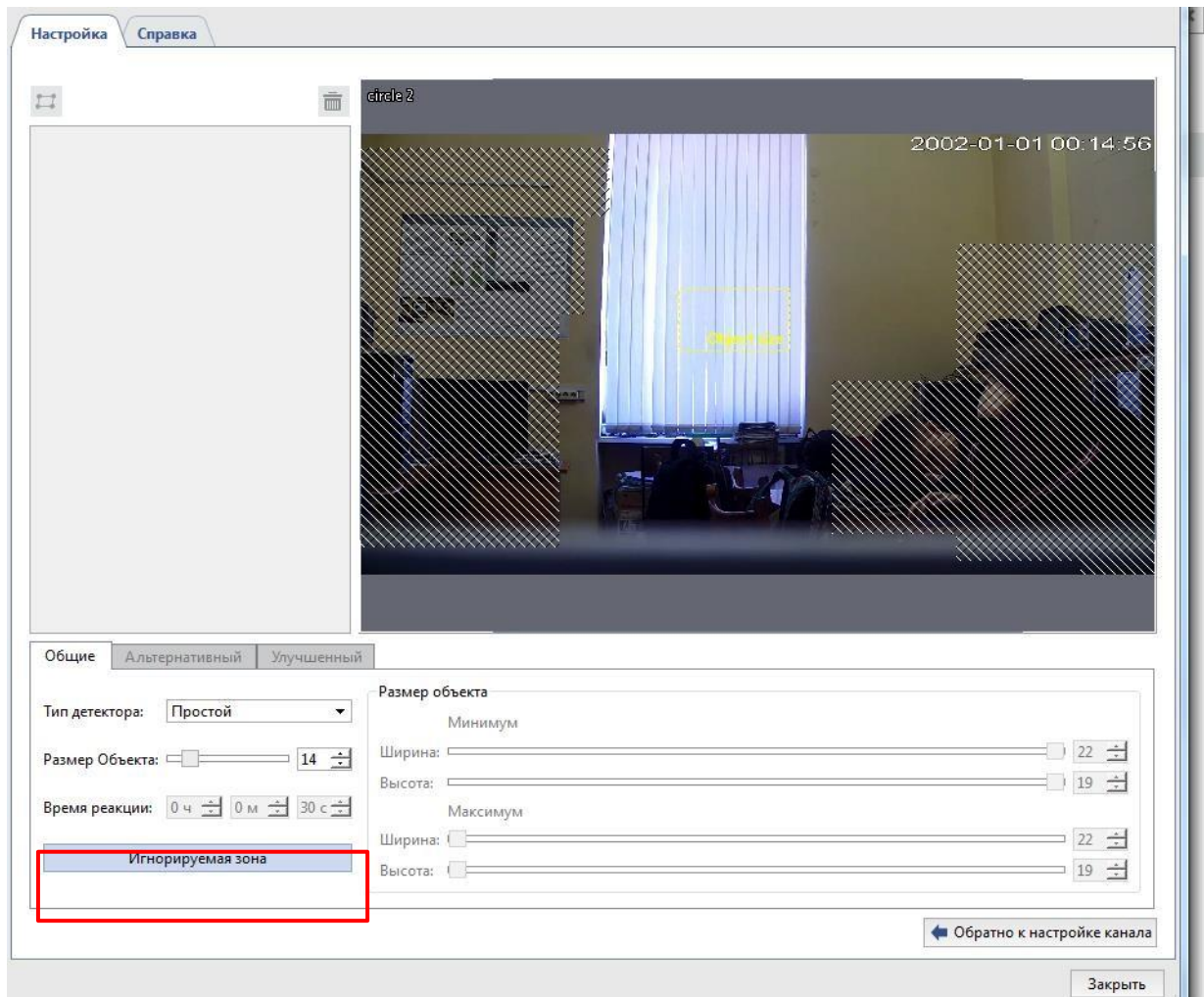


Figure 3.14 – Creating Ignored Zones

Using the **Object Size** setting, determine the approximate size of the object to which the detector will react.

Objects significantly larger than the size indicated in the image will be ignored. A yellow rectangle labeled Object size in the image (Fig. 3.14) will help you estimate the size of the object to be detected.

If the detector is set up correctly, the objects left behind will be highlighted with a red rectangle. Figure 3.15 shows an example of the correct detection of an object (a dark car) that appears in the frame and is marked with a red frame labeled Left Object [29].

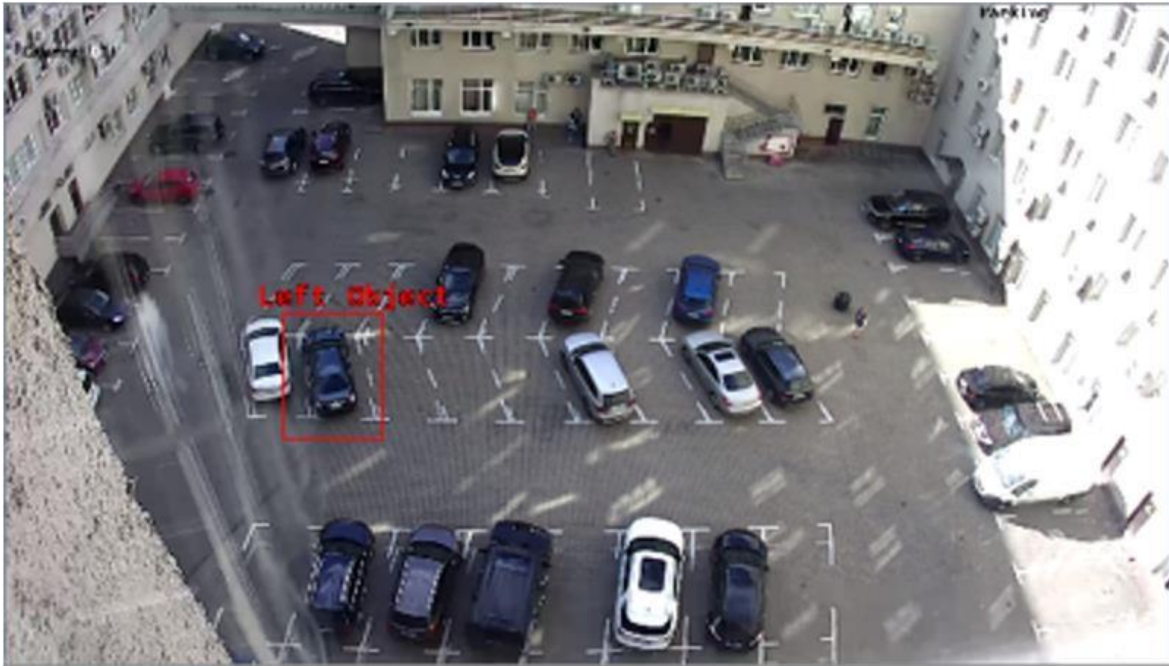


Figure 3.15 – Example of correct detection of an object

To switch to the general settings of the Advanced detection algorithm, select the detector algorithm from the **Detector type – Improved** drop-down menu in the **Settings** window on the **General** tab (Fig. 3.16).

Next, using the **Object size** settings, you can determine the **minimum** and **maximum** size of the object to which the detector will react. Rectangles in the image will help you estimate its size. The detector will work if the object left behind is larger than the green rectangle, but smaller than the yellow one (Fig. 3.16).

The Sensitivity **parameter** determines the sensitivity of the detector. **Reaction time** is the time that will elapse from the moment an abandoned object is detected until it is notified.

To continue configuring the Enhanced Detector, go from the **General** tab to the **Advanced** tab. The Enhanced Abandoned Object Detector also analyzes videos using two algorithms: **Simple** and **Enhanced**.

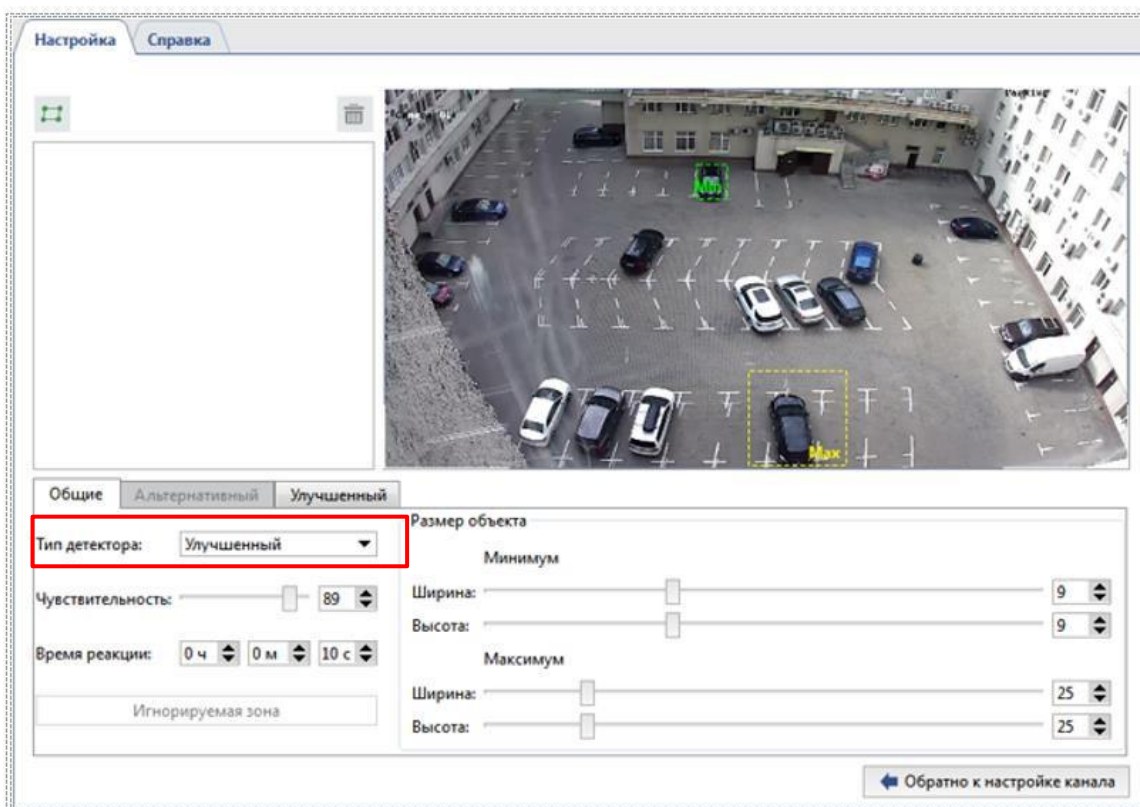


Figure 3.16 – General settings window of the improved detector algorithm It is recommended to start with **a simple** algorithm (Fig. 3.17).

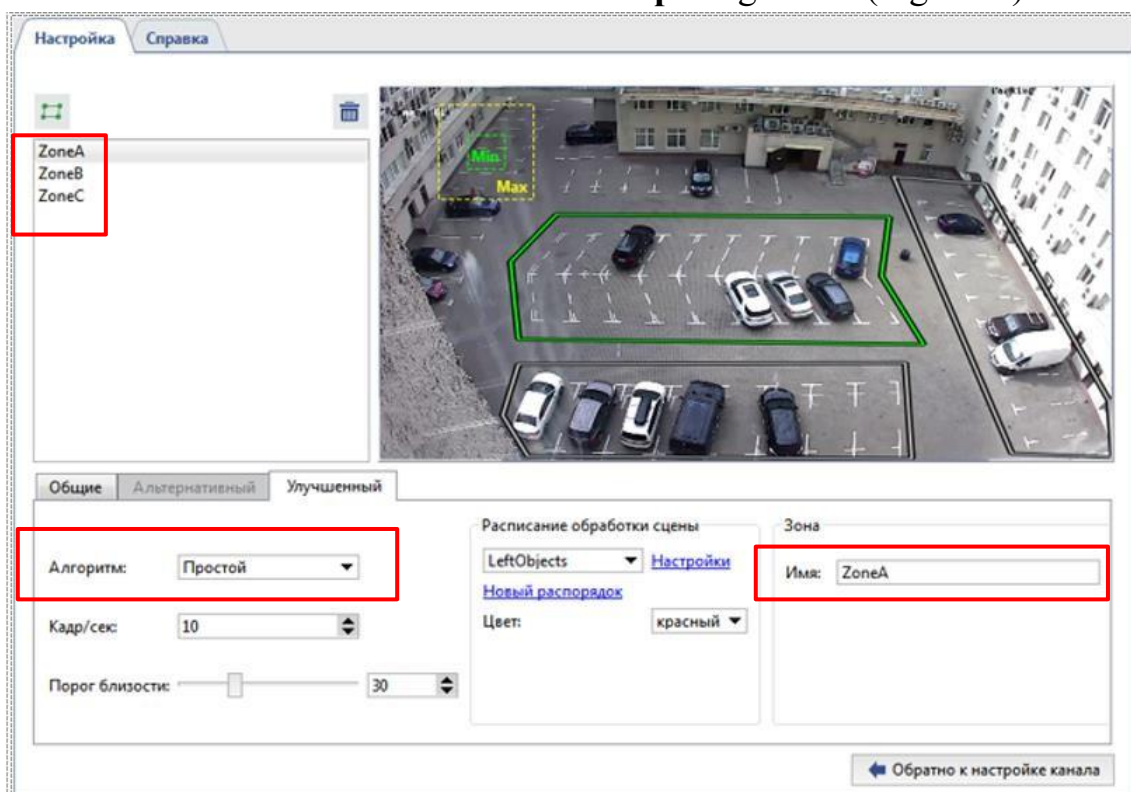


Figure 3.17 – Settings window of the simple algorithm of the improved detector of abandoned objects [29]

The Frame/sec **setting** determines the speed at which the detector will try to detect abandoned objects. In the **Proximity threshold setting**, you can specify the approximate distance between the person and the object that he left behind. If this distance is exceeded, the detector will consider the object to be abandoned. When changing the setting, images appear on the video from the camera, with the help of which you can estimate the distance between the object and the person (Fig. 3.18).



Figure 3.18 – Setting the distance for the improved algorithm

Click on the New schedule link to create a new schedule or on the **Settings** link to change the existing one. In the **Color** field, select the color of the schedule area during which the abandoned items will be detected. For a detailed description of the schedule creation process, please refer to the Trassir User Manual section of the *Schedule* [30].

Select the areas of the image in which the objects left behind will be tracked. To do this, click the button  and click on the left mouse button to specify the vertices of the polygon. When finished, click the Finish button. If necessary, enter a name for the zone (the name of the Zone A is highlighted in red in Figure 3.17).

If the detector is configured correctly, the detected abandoned objects will be highlighted in the images with red rectangles. If false positives occur as a result of the detector, change the algorithm to **Improved**.

Configure the parameters for each of the detector algorithms and save screenshots displaying the sequence of your actions and their results.

IV. Conduct an experimental study of the module of abandoned objects by simulating various conditions for its operation, for example: varying the size, color, number of objects; changing the parameters of the module settings (sensitivity, sizes and configurations of detection zones, reaction time) or observation conditions and scene structure.

Below are examples of incorrect operation of modules at different settings and scene parameters.

For example, Figure 3.19 shows a false selection of a person as an abandoned object. To prevent this error from happening again, choose a smaller size of the abandoned object or change the ignored zone.

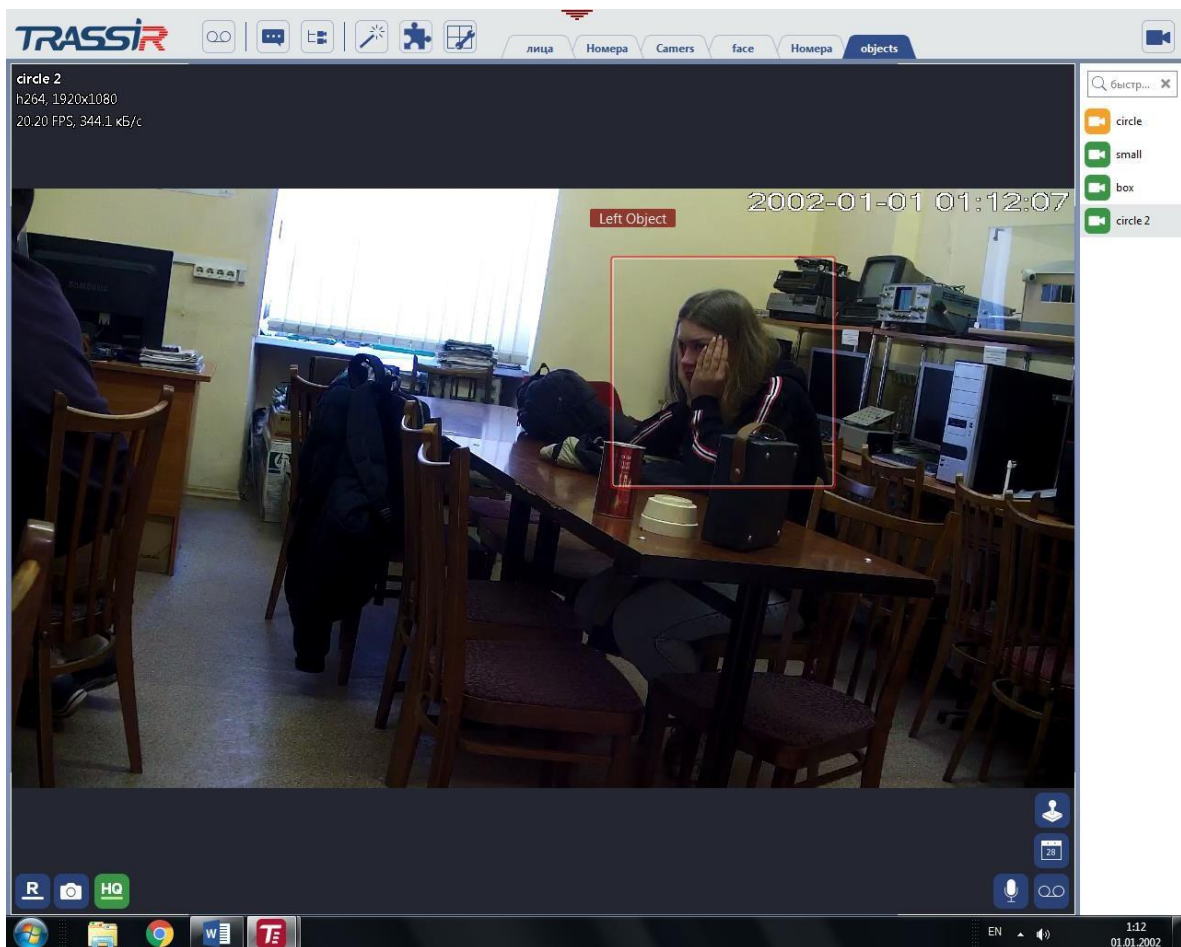


Figure 3.19 – False selection of a person

It is also worth noting that the camera does not record an item as abandoned if the item is smaller than the tuning green dotted line

frame that corresponds to the minimum size of the object (Figure 3.20)

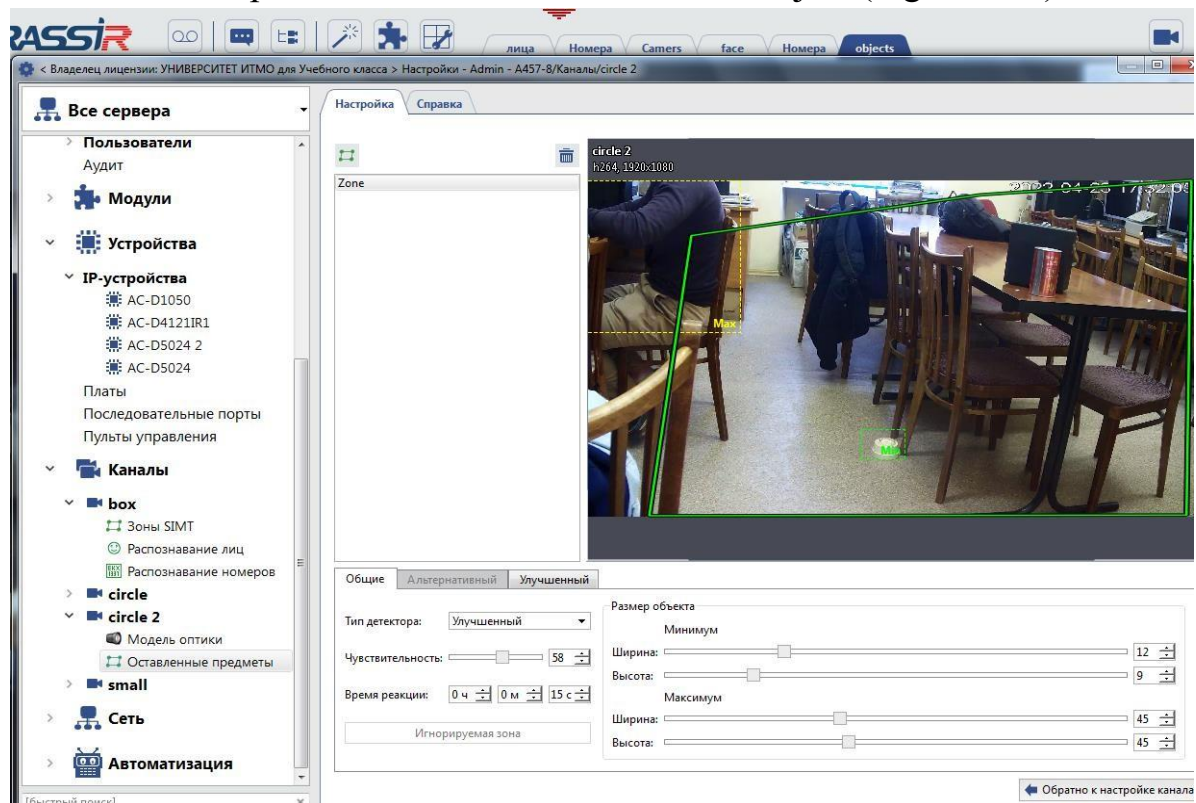


Figure 3.20 – Incorrect object size setting

Figure 3.21 shows the incorrect result of the module's operation with a complex configuration and local scene dynamics.



Figure 3.21 – Ignoring the object left in the frame

When the position of the chairs changes within the specified recognition time, the system begins to record them as abandoned objects, while ignoring the sample abandoned object (white smoke detector on the laboratory floor).

As the number of abandoned items increases, the system recognizes one out of four and gives one false alarm (Fig. 3.22).



Figure 3.22 – Identification of several abandoned objects An increase in the sensitivity of the algorithm leads to an increase in false Triggers: one item out of four was correctly detected (Fig. 3.23).

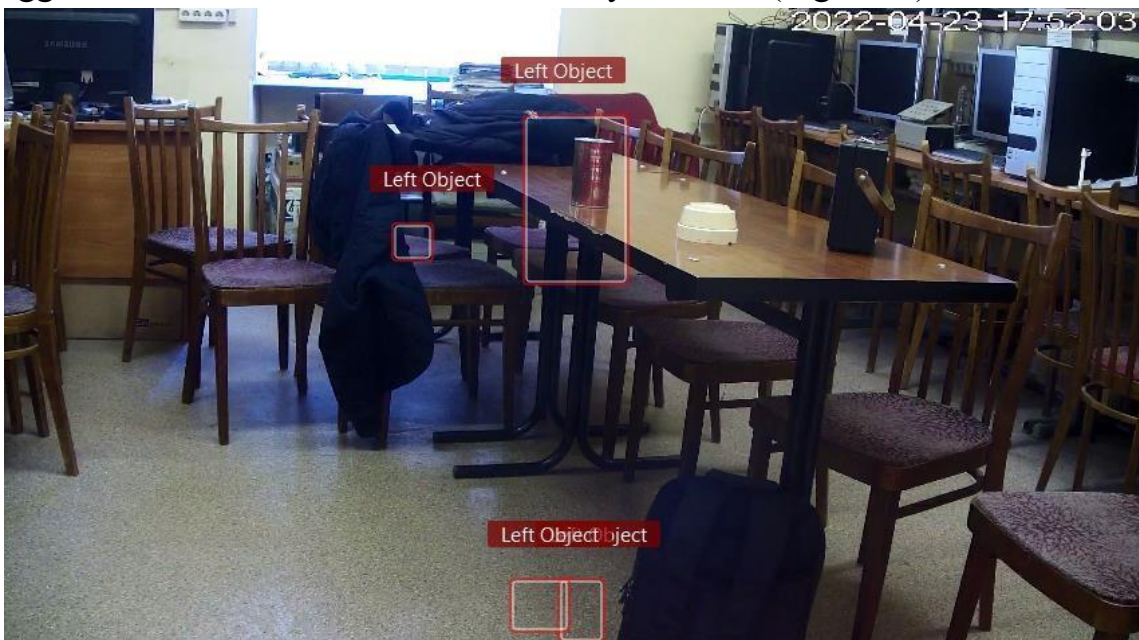


Figure 3.23 – False discharge with increased sensitivity

With an increase in the waiting time and an increase in zoom, we get no false alarms, but the selection of two objects as one (Fig. 3.24).



Figure 3.24 – Selecting two objects as one abandoned object If you leave the objects 15 seconds after there was no one abandoned object, then we get 4 correctly detected objects, 1 undetected (video camera) and 1 false detection (Fig. 3.25).

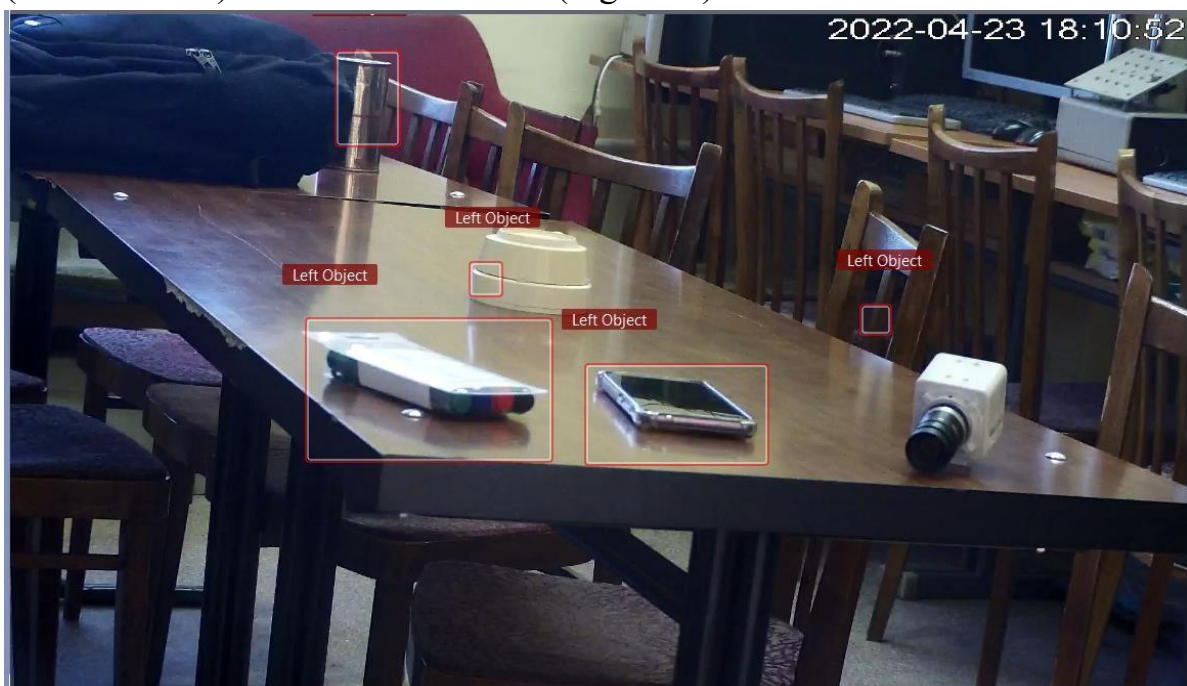


Figure 3.25 – Detection of multiple objects

If abandoned items are found incorrectly, the settings must be adjusted.

Document the results of the experimental study of the abandoned items module by taking appropriate screenshots for the various algorithms and specifying the numerical values of the set parameters.

Systematization of materials by compiling a summary table containing information about the results of the module, current parameters and their corrections to adjust the work of the module is welcome. Prepare materials for the report

V. Turning off the laboratory unit is carried out in the reverse sequence of its activation.

Contents of the report

1. Brief information about the methods of searching and finding abandoned objects.
2. The results of setting up module modifications in the form of screenshots of software windows with a description of the sequence of actions.
3. The results of the work in the form of screenshots of software windows and summary tables with the results of observations.
4. Brief conclusions on the work.

Control questions

1. What are the features of image processing to solve the problems of finding and locating abandoned objects?
2. What is the structure and functionality of the detector of abandoned objects in the Trassir program?
3. Explain the algorithm for setting the main modes of operation of the video analysis module in the Trassir system. How are the functions distributed between the different modifications?
4. What determines the configuration and size of the detection zones formed when configuring the Abandoned Item module on the channel?
5. How do the algorithm settings and observation conditions affect the operation of the module?

Practical lesson No4. Study of the video module for building the trajectory of objects in a video stream

Objectives of the work:

1. To study the theoretical issues of tracking methods for one video camera.
2. To study the purpose, structure, applications, interface of the intelligent SIMT module based on Trassir software.
3. To study the functional features, configuration procedure and main modes of operation of the SIMT detector.
4. Gain practical skills in setting up equipment, working with an intelligent SIMT detector and determining its main characteristics.

Brief theoretical information

One of the most complex and urgent tasks of video image processing in computer vision systems is the problem of identifying and recognizing moving objects in the presence of various types of interference and creating monitoring systems on this basis. The main task of such systems is to inform the user about the situation in the camera's field of view, and, if possible, to take any pre-planned and program-based actions.

The process of building these systems is a complex technological chain that includes obtaining a digital image, processing it in order to identify significant information and analyzing this information to solve a certain problem.

To work with moving objects, intelligent software detectors are created, the main functional tasks of which are as follows:

- to distinguish an object with given parameters against the background of numerous and stochastic motion, which in most cases is noise;
- form and visualize the trajectory of the detected object based on the processing of the video sequence, taking into account possible changes in its speed and direction of movement;
- ensure object tracking in changing conditions of a dynamic scene, taking into account possible overlap

object being traced by other road users and its temporary disappearance from the frame.

An important part of computer vision systems is a tracker - an algorithm for tracking the position of an object on a video sequence over time. The main area of application of object tracking video modules is to ensure safety in situations in which movement is an alarming event that requires attention, for example:

- protection of perimeters and open areas;
- protection of parking lots and oil pipelines;
- security of lobbies of metro stations and transport hubs.

Motion detectors with object tracking are also in demand in video surveillance systems when intelligent situational awareness is required, such as detecting a running person in a place where running is not the norm, tracking the movements of athletes in team games, recording the trajectory of the ball in tennis or football when scoring an opponent's goal.

The trajectory of a material point is a line in space along which a body moves, which is a set of points at which a material point was, is or will be located when it moves in space relative to the chosen frame of reference. When constructing the trajectory of an object in the field of view of one camera, the problem is considered, which can be formulated as follows [31].

In the video stream W_k , consisting of a sequence of images I_k of the observed scene $W_k = \{I_k, k = 1, 2, \dots\}$, it is required to select a set of moving objects $A_k = \{a_i\}$ within the scene W_k , identify each a_i , determine the trajectory of movement $a_i(x, y, k)$ in the observed scene, determine the parameters of movement $c_i(x, y, k)$ along these trajectories and by comparing them with the permissible values $c^*(x, y, k)$ determine the threat of an emergency situation with the issuance of the corresponding message. In this case, image processing includes the following stages:

- 1) highlighting the foreground;
- 2) identification and classification of moving objects;
- 3) tracking the trajectory of the found objects;
- 4) recognition and analysis of the actions of objects of interest.

The process of selecting the foreground consists in separating moving fragments of the image from still ones, which are called background or belonging to the background. All subsequent stages of information processing, as well as the required computational resources, depend on how correctly this task is solved. To build the foreground, the most commonly used methods are based on background subtraction, probabilistic methods, time difference and optical flow methods [32,33].

Difficulty Discharge Background explained big
a variety of factors, such as the camera's own noises, a sudden
change in illumination scenes, Falling shadows, Movement
tree branches in the wind and others.

In the second stage of selection and classification, the foreground image is first segmented, that is, there are compact areas moving at the same speed, which are considered moving objects. Next, they are correlated with predetermined classes: cars, people, animals.

After that, the next stage can be performed - tracking the trajectory of each moving object. The stage of selecting trajectories is called tracking. To carry out tracking, it is necessary to establish a one-to-one correspondence between the detected objects in successive frames. This provides temporary identification of the selected areas of the image and provides relevant information about objects in the observed area, namely: trajectory, speed and direction of movement. There are various approaches to predicting the trajectory of movement, among which the method of simple interpolation, the method of additive transformation and the Kalman filter are common [33, 34.].

At the final stage, the actions of the selected objects are recognized and analyzed. Ideally, the system should issue messages about the detection of an emergency situation such as:

"The distance between cars is decreasing too quickly", "A traffic jam has formed at the intersection".

Thus, on the Login tracker A video
sequence and some initial position of the object or objects are received, which can be evaluated automatically or specified by the user. The tracker allows automatic

get an assessment of the position of the object in all subsequent frames (provided that it is present in them).

Most trajectory construction methods can be expressed as a functional minimization problem, the key factor of which determines how likely it is that a group of detections will correspond to one object. This factor describes the similarity of detections within a group and is based on solving the verification problem.

One of the algorithms for searching for an object in an image is based on the use of a reference image of the object being tracked [7]. The search for an object in the image itself is carried out by minimizing the function of distinguishing the species

$$F_n(i, j) = \sum_{i,j \in H_n} |l(i + \alpha, j + \beta, n) - h(\alpha, \beta, n)| ,$$

where n is the frame number; $l(i, j, n)$ is the brightness values of the elements of the analyzed image L_n in the n -m frame; $h(i, j, n)$ are the brightness values of the elements of the discrete reference image of the object H_n ; i and j are the coordinates of the center of the object in the coordinate system of the image L_n ; α and β are the coordinates of the points of the object in the coordinate system associated with the center of the object.

When accompanying people, in many cases, it is impossible to apply methods of verification of a person by the image of a face, since it can be hidden or have a low resolution. Therefore, probabilistic models containing information about the position of people in the frame and the speed of their movement are widely used in tracking methods [35].

Tracking methods can be divided into two classes:

1. Single-hypothesis methods allow you to track only one possible trajectory;
2. Multihypothesis methods allow you to track several trajectories and choose the best one.

The principle of operation of the mean shift algorithm is based on the search for the maximum probability density of a certain function describing discrete image data. When estimating the probability density function, a kernel denoted $K(x_i - x)$ is used. The kernel determines the weight of various points when estimating the mean.

$$K(x_i - x) = e^{-c\|x_i - x\|^2}$$

The weighted average is calculated using the formula:

$$m(x) = \frac{\sum_{x_i \in N(x)} K(x_i - x) x_i}{\sum_{x_i \in N(x)} K(x_i - x)} ,$$

here $N(x)$ is the neighborhood of point x , a set of points for which $K(x) \neq 0$. The algorithm makes an estimate for points $x \leftarrow m(x)$, and repeats the estimate until $m(x)$ stops changing.

Compared to more complex multi-hypothesis methods, the advantage of this approach is high computational efficiency, the disadvantage is lower tracking accuracy. The results of this approach can be improved by using additional information, such as optical flow – estimates of instantaneous velocity for each pixel of the frame.

Optical flow-based methods compute the motion between two frames taken at time t and in each pixel. These methods are called differential because they are based on the approximation of a signal by a segment of the Taylor series; thus, they use partial derivatives of time and spatial coordinates.

In the case of dimension $2D+t$, a pixel at position (x, y, t) with intensity $I(x, y, t)$ will be moved by $\delta x, \delta y, \delta t$ in one frame, and the following equation can be written:

$$I(x, y, t) = I(x + \delta x, y + \delta y, t + \delta t)$$

The following equation can be used to estimate the velocity V of pixel motion $\nabla I \cdot V = -I_t$. This equation contains two unknowns and cannot be unambiguously resolved. The problem is solved by imposing additional constraints — regularization.

Algorithms that allow you to quickly calculate the optical stream for each frame of a video sequence.

For moving objects, the optical flow is more important than for a stationary background and allows you to find foreground objects in the video sequence.

SIMT software detector included in Trassir software

A TV system based on Trassir software contains a channel-by-channel licensed intelligent video module SIMT (Simple Intelligent Motion Trassir), which is designed to detect the movement of objects in a video stream with the support of their tracing in the field of view of the video camera. The detector allows you to select from the entire image only really moving objects with specified parameters, with their own history and nature of movement, as well as to distinguish these objects from each other. An object that has disappeared from view for a short time (for example, behind

tree) will not be mistaken for a new or different object. SIMT is able to filter out interference caused by swaying tree branches, snow and rain, and slight camera shakes [37].

The SIMT module provides:

- high resistance to precipitation, interference and noise;
- detection of speed, direction of movement, distance traveled and size of actually moving objects;
- control of the crossing of the boundaries set by the operator;
- control of the location of objects in the zone formed during the setup;
- automatic control of PTZ cameras (when working in conjunction with the ActiveDome module).

Composition of the laboratory unit

The work is carried out on the basis of a universal laboratory complex of network video systems (ULK SVS), the description of which is presented in Paper No 3 of this manual. Before starting work, it is necessary to configure the server and client parts of the Trassir software, determine the number of workstations and cameras involved for the workshop.

Procedure for performing work

The work is designed for 4 hours and includes the following sections:

- switching on the laboratory unit and preparing it for operation;
- Connecting and configuring the camera to be used as part of the SIMT smart detector
- Mastering the SIMT Smart Detector Setup Methodology:
 - create and edit boundaries;
 - creating and editing control zones;
 - setting up ignore areas;
- experimental study of the functionality and algorithms of the SIMT module;
- Shutdown of the laboratory unit.

I. The laboratory unit is switched on and prepared for operation in the following sequence:

- supply power to video cameras;
- Turn on the computer using the button on its front wall.

- After turning on the computer, Windows will automatically start and the pre-installed Trassir Server software will automatically start.
- if there is a hierarchical structure of the Trassir system, it is necessary to create Users for computers with the Client status on PC Server and delegate to them the rights to work with analytics via the network (see the methodology within the description of the ULC SHS)

II. To connect and configure any of the built-in detectors of the Trassir software for the selected channel (IP camera), go to the **Channel settings** in the **Software detectors** area. Next, to work with the SIMT detector, go to the **Motion detector option in the group of parameters in the Software detectors area (fig.4.1)**, select the Motion detector (SIMT) *item from the drop-down menu*.

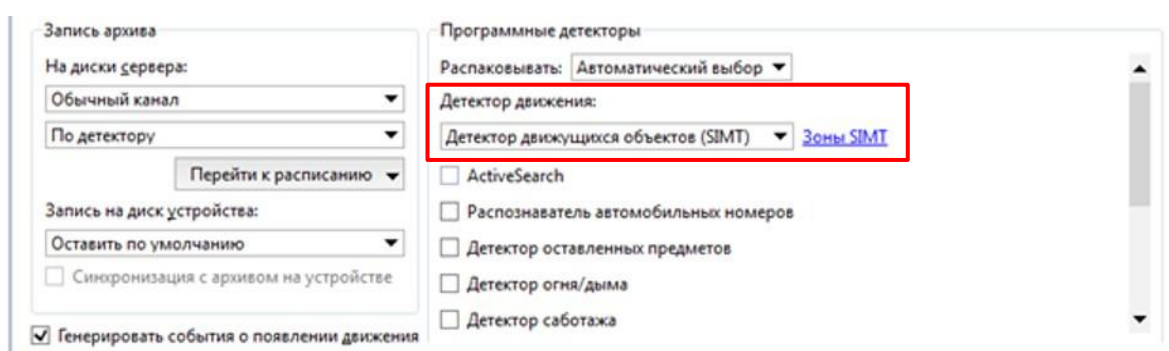


Figure 4.1 – Connecting the SIMT module

III. Configuring the SIMT

Setting up the detector consists of creating control zones and boundaries in which the tracing of moving objects will be implemented, as well as areas of ignorance to limit the detector's action.

To start creating inspection zones, click on the *SIMT zones link*. The SIMT detector boundaries and zones settings window will open.

Creating a Boundary in an Image

The **boundary** is the line that bounds the detector's area of operation. In Figure 4.2, the boundary line is shown in green. The boundary is defined using an open polyline. Event

The detector is generated when an object (in this case, a person crossed the border) crosses one of the specified lines.

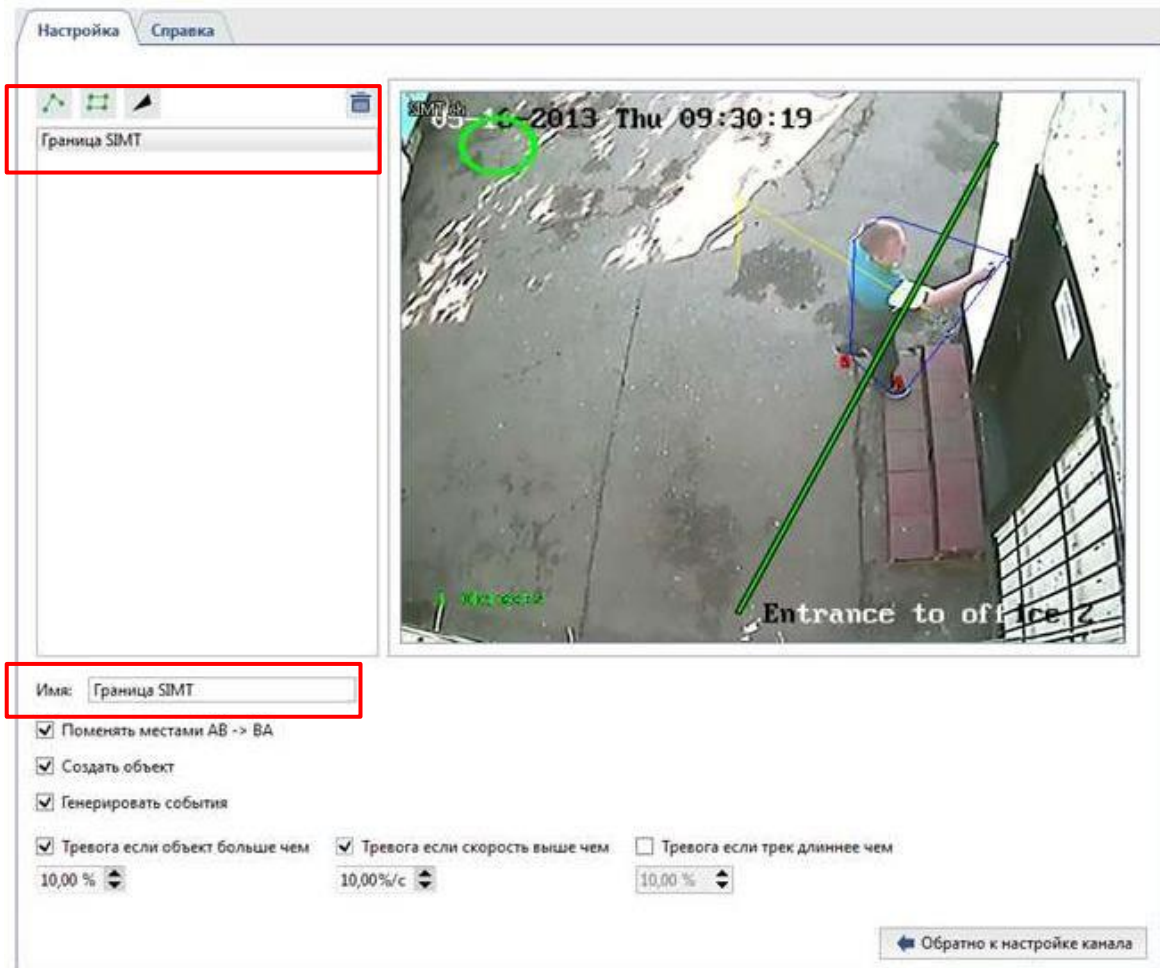


Figure 4.2 – Setting the boundaries of the detector operation

[37] To add a boundary, you need to:

- click on the button  ;
- sequentially click on the left mouse button to set the vertices of the open polyline;
- click on the *Finish button*;
- Set intuitive **SIMT boundary** name
- Select *the Swap* AB -> BA checkbox to swap the boundaries A and B if necessary.
- Check the *Create feature* flag if you want to create a "feature boundary" to be monitored using the Trassir feature tree.
- check the *Generate events flag* if you want the "Unit crossed boundary" events to be generated and written to the database when crossing the border (in this case, the event will contain

- direction of movement, which will allow you to determine from which side the object crossed the border);
- set the flags and values of the object parameters for *the Alarm options if the object is greater than*, *Alarm if the speed is higher than* and *Alarm if the track is longer than* if it is necessary to issue and write to the database additional alarm events depending on the characteristics of the moving object.

Creating a SIMT detector monitoring area

A **zone** is an area that bounds the area of the detector's operation. A zone is defined by its boundary, which is a closed polyline - a polygon. In Figure 4.3, the lines of the zone border are shown in green.

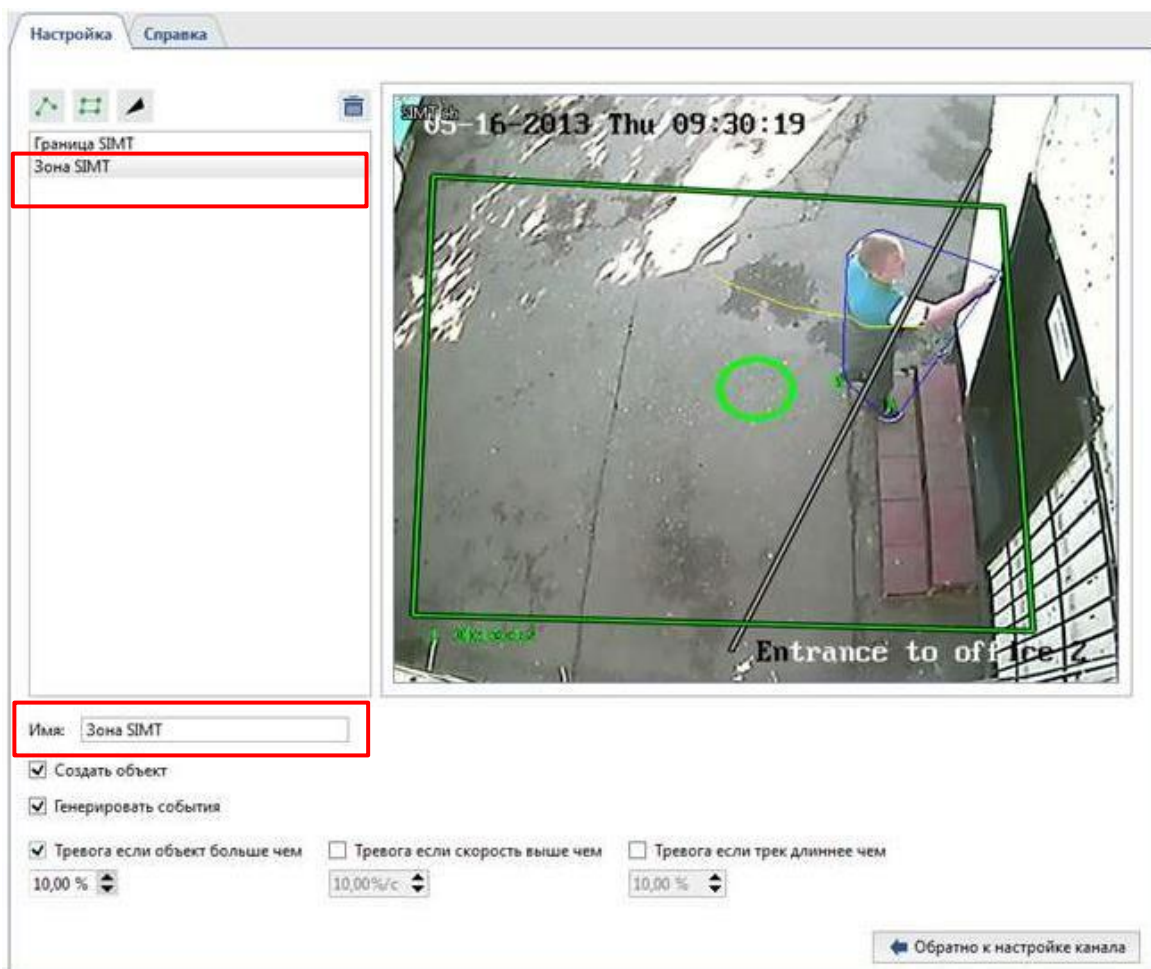


Figure 4.3 – Setting up the detector operation zones [37]

Detector Zone - The area that will be monitored by the detector when motion occurs in it. A detector event can be generated when there is movement inside a given polygon.

To add a detector zone, you need to:

- click on the button ;
- sequentially click on the left mouse button to set the vertices of the polygon;
- click on the *Finish button*;
- set an intuitive **Name** for the detector area;
- check the **Create object** flag if you want to create an object in the TRASSIR object tree for this zone. The object zone can be used when organizing monitoring using the object tree (CMS) and the corresponding filters.
- select the **Generate events** flag if you want the "Unit entered zone" and "Unit out of zone" events to be generated and written to the database when driving in this zone.
- set the flags and values of the unit parameters for *the Alarm if the unit is larger than*, *Alarm if the speed is higher than* and *Alarm if the track is longer than* if it is necessary to issue and write to the database additional alarm events depending on the characteristics of the moving unit.

Creating a SIMT Detector Ignore Zone (Region)

The ignore zone is an area in which no action will be performed by the detector when there is movement . The ignore zone is defined by the vertices of the polygon. In Figure 4.4, the border of the ignore zone at the top of the image is indicated by a green rectangle.

To add a Ignore Zone, you need to:

- click on the button ;
- sequentially click on the left mouse button to set the vertices of the polygon;
- click on the *Finish button*;
- Set an operator-friendly **Name** for the Ignore Zone.

Editing SIMT Detector Zones and Boundaries

After you define zones and boundaries, you can adjust the position of their vertices, remove unnecessary vertices, or add new vertices.

To edit a zone (boundary), you need to:

1. Select a zone (boundary) in the list. The currently selected zone (boundary) is highlighted in green, the rest of the zones (boundaries) are highlighted in gray.

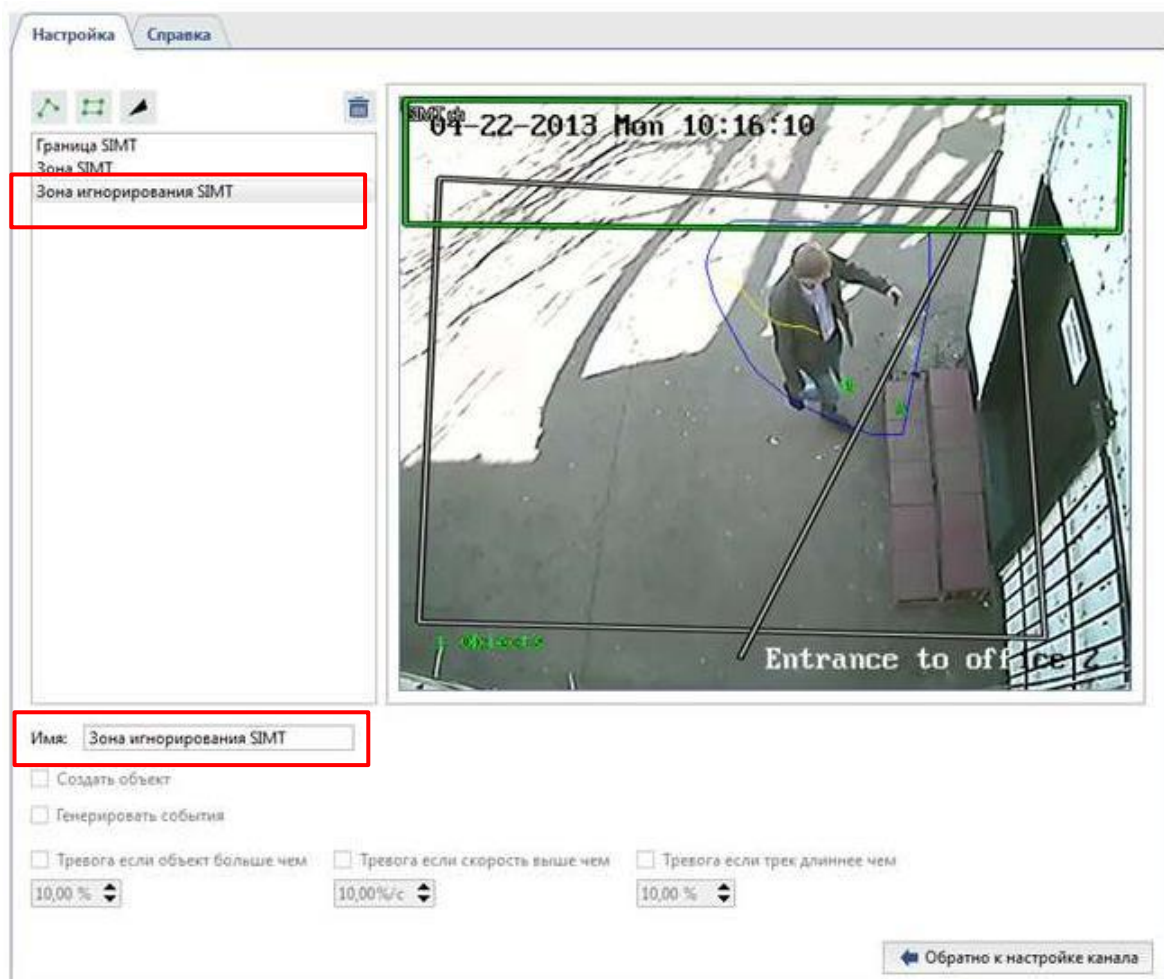


Figure 4.4 – Setting up the ignore zone [37]

2. Click on the left mouse button in the vertex area (marked with a yellow oval).
3. Without releasing the left mouse button, adjust the position of the vertex.
4. If the vertex is not needed (highlighted with a yellow oval in Figure 4.5), you can remove it. To do this, you need to:
 - hover the mouse pointer over the area of the yellow oval;
 - click on the right mouse button;
 - in the context menu that appears, select **Delete Point**.

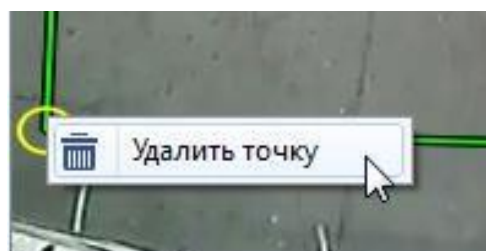


Figure 4.5 – Configuring the deletion of a zone point or detector boundary

5. To add a new vertex to an existing zone (boundary), it is necessary (Fig.4.6):
- hover the mouse pointer over the proposed location of the new peak;
 - click on the right mouse button;
 - in the context menu that appears, select **Add point**.

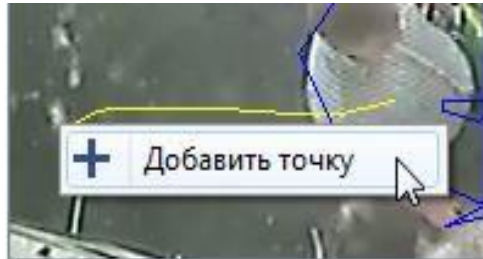


Figure 4.6 – Setting up the addition of a detector zone point or boundary

V. Conduct an experimental study of the SIMT detector by simulating various conditions for its operation, for example: varying the size, color, number of objects; changing the parameters of the module settings or observation conditions and the structure of the scene.

Below is an example of the module's operation when it is activated, but in the absence of channel settings. By default, there are no ignore zones, the borders and control zones coincide with the image in the frame (Fig. 4.7).

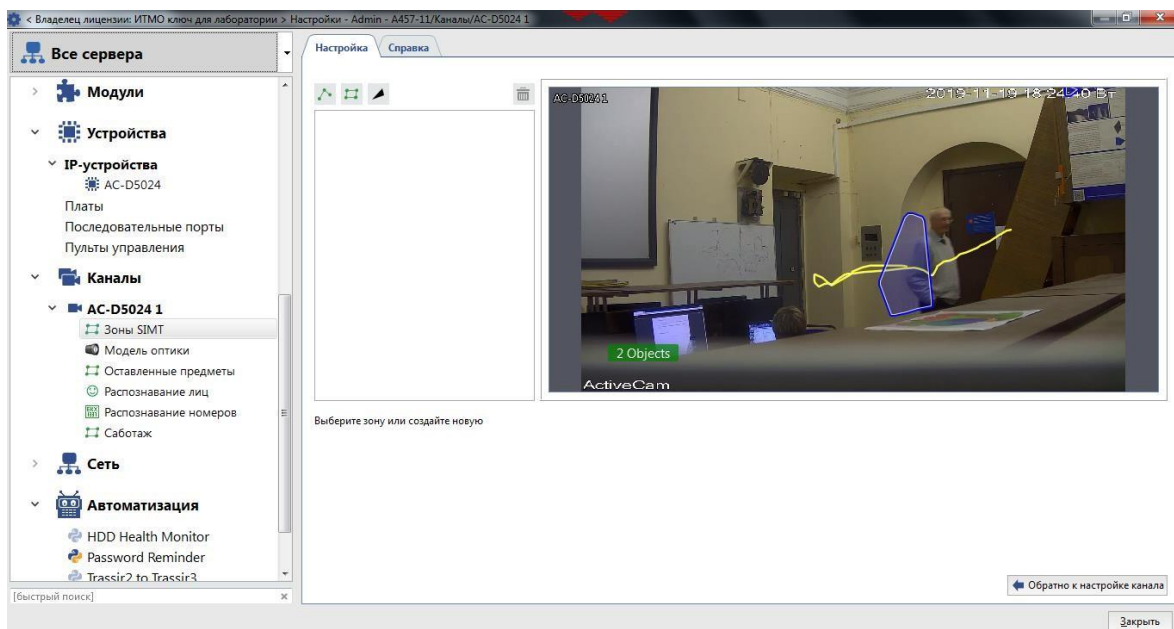


Figure 4.7 – Example of detector operation in the absence of settings

When conducting research, it is recommended to create a template to display the operation of the module. When configuring a template that contains a window

SIMT detector, you will be able to observe the results of the detector's operation (Fig. 4.8).

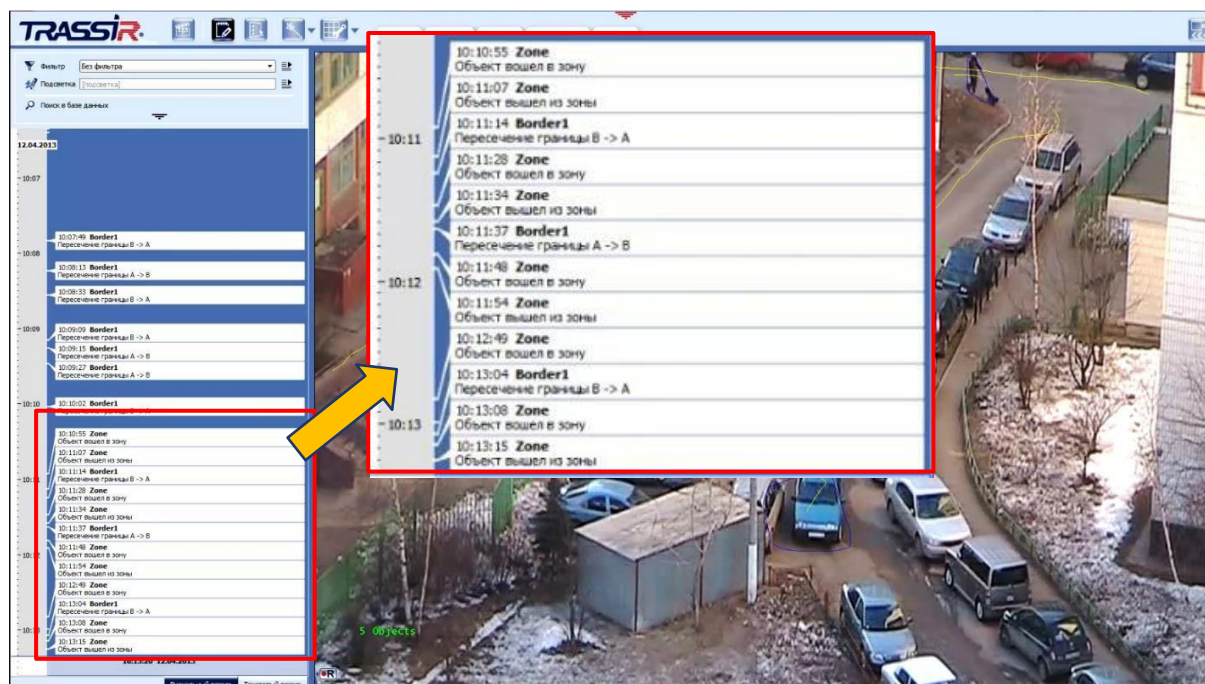


Figure 4.8 – Example of the SIMT detector working and displaying the results in the event log

Information about the detector response time and the directions of movement of the monitored objects with the names of boundaries, crossed objects, and intrusion zones will be displayed in the event log (on the left side of the interface of the template window). Instructions on setting up the template can be found in the manual [28], as well as on the website of the Trassir software manufacturer.

Document the results of the SIMT pilot study by taking screenshots and numerical values of the parameters set.

It is recommended to systematize the materials of the study of the video module by compiling a summary table containing information about the results of the tracker operation, current settings parameters and their corrections to adjust the work of the module. Design materials for the report using saved screenshots.

V. Turning off the laboratory unit is carried out in the reverse sequence of its activation.

Contents of the report

1. Brief information about the methods of searching and finding abandoned objects.
2. The results of setting up module modifications in the form of screenshots of software windows with a description of the sequence of actions.
3. The results of the work in the form of screenshots of software windows and summary tables with the results of observations.
4. Brief conclusions on the work.

Control questions

1. What are the features of image processing to solve the problems of detecting and tracking objects in a video stream?
2. What is the Structure and Functionality of the detector SIMT in Trassir?
3. Explain the algorithm for setting the main modes of operation of the video analysis module in the Trassir system.
4. What determines the configuration and size of the detection zones formed during the SIMT module settings on the channel?
5. How do module settings and monitoring conditions affect the module's operation?

Laboratory Work №5. Research robotic video control system for PTZ cameras

Objectives of the work:

1. To study the theoretical issues of automated video control in the detection and tracking of objects.
2. To study the structure, interface, principles of operation of a video module for object recognition and robotic control of cameras as part of a television system based on TRASSIR software.
3. To study the functionality, configuration features and basic modes of operation of the ActiveDome module.
4. Gain practical skills in setting up and operating the module for interactive control of high-speed PTZ cameras.

Brief theoretical information

Machine vision is one of the key areas of research in today's multi-camera video surveillance systems. With the development of technology and the increase in the number of video cameras, the need for effective recognition and analysis of events occurring in the environment has increased. Motion recognition modules play an important role in this field, allowing you to detect and track moving objects in real time.

Modern analytical video surveillance systems with elements of artificial intelligence include many video cameras, some of which are fixed, some are mounted on rotary devices, and automated PTZ cameras, as a rule, have a controlled magnification. Video cameras are connected to one or more unified local area networks (LANs), the purpose of which is to process and analyze video signals.

Mobile and stationary video cameras, as well as servers that process video signals and control PTZ cameras, are combined into equipment of one surveillance zone according to the principle of territorial proximity, which allows you to connect servers with a high-speed network, and organize the transmission of video and control signals between cameras and PCs. One of the main features of an analytical video system is the use of rather complex

algorithms and methods for processing images obtained from video cameras in order to automatically identify situations in the field of view of cameras that are of interest to operators.

Another feature of analytical video systems is the interaction of PTZ cameras and stationary cameras based on their coupling to obtain more detailed images of events in the observed area.

Pairing a stationary camera and PTZ camera pair is a function search operation that compares for each area of the still camera image such control parameters and such magnification and focus values of the PTZ camera lens that, when these parameters are applied, the PTZ camera image is focused for this area with optimal magnification. Figure 5.1 illustrates the pairing of a stationary camera and a PTZ camera [38].

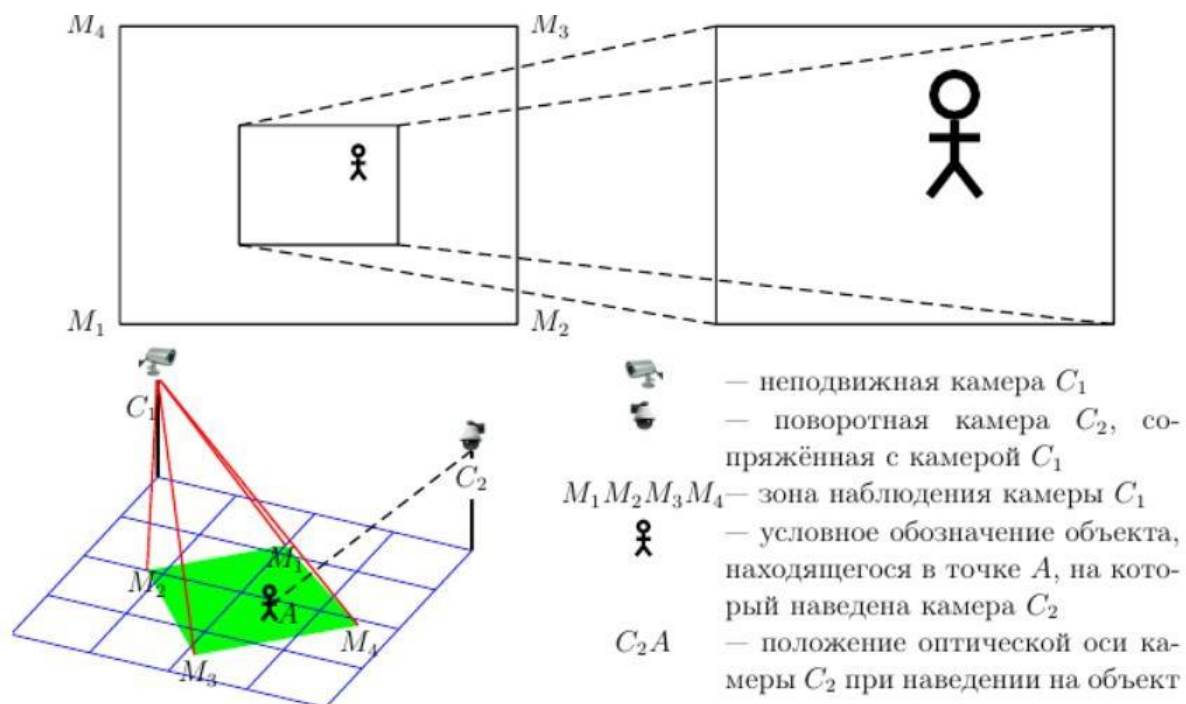


Figure 5.1 – Diagram of the interface of fixed and PTZ cameras

On the left in the figure is the image of the object on the fixed camera C_1 . On the right is the enlarged image on the paired PTZ camera C_2 . On the still video camera C_1 , the area containing the image of a person who is in the observation area $M_1M_2M_3M_4$ camera C_1 is highlighted. The PTZ camera C_2 is pointed at the selected area and produces an image with high magnification and better

resolution. The orientation of the C2A axis is determined by the rotation angles, and the magnification is determined by the control parameters of the C2 camera.

The PTZ camera control parameter values that specify the targeting of the desired area are derived from the pairing of cameras based on the mapping of their images. Camera images can be matched based on common features such as unique points, textures, and object boundaries, or by using calibration data such as calibration matrices and distortion factors.

To form a calibration matrix, a coordinate grid of control points is built on the image from the overview camera. Creating such a grid requires knowledge of camera parameters such as position, orientation, focal length, and distortion factors to determine the correspondence between different pairs of cameras. For this purpose, geometric rectification or epipolar geometry methods are usually used [39].

The epipolar geometry method is a powerful tool for analyzing and combining information from multiple cameras. It is based on the geometric principles of projection and the relationship between two images of the same scene obtained from different cameras. The method allows you to relate the projection positions of a point in three-dimensional space on images from both cameras.

The main concepts of the method are the epipolar line (this is a line in one image that corresponds to a point in another image on which the beam passing through the point in the first image and the optical center of the second camera is projected) and the epipolar plane (this is the plane that contains all the epipolar lines for each point in one image).

Figure 5.2 shows the path of rays originating at different points and converging at one point P. This point corresponds to the object we are observing from two different points. In this case, points O1 and O2 correspond to the spatial position of two particular observers. The lines O1P and O2P are epipolar.

For a given point in one image, you can find the corresponding epipolar line in another image, and then find the point corresponding to the original point in that image. This allows you to link the points in the two images and create a calibration grid from them.

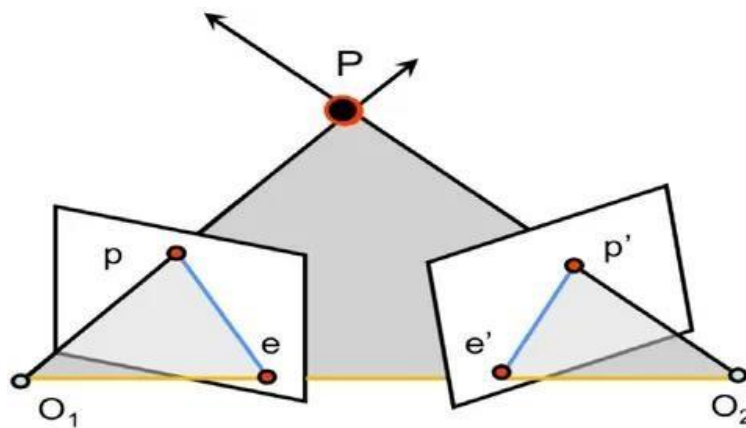


Figure 5.2 Lines of epipolar geometry

Rotary video camera, in which Implemented magnification which can be used to increase the resolution of images in the surveillance area, and select only those necessary for operator control from the event stream in the surveillance area. Combining information from multiple cameras and creating a mesh allows for a more complete and extensive view of the scene, which can be useful for various applications, such as object tracking, face recognition, and behavior analysis. Evaluating results Mappings cameras and Creation Meshes Produced by at the user level – visually, using high-quality parameters.

However, when creating automatic computer vision systems, it is important to theoretically assess the reliability of the output data of the interface, synchronization and semantic classification algorithms [38].

When pairing a PTZ and a stationary camera, it is necessary to find a correspondence between the image coordinates (x, y) of the fixed camera and the rotation angles (α, β) of the optical axis of the rotating camera in some polar coordinate system with the origin at the point of mounting the camera (additionally, the parameters of the lens magnification are determined in accordance with the angular dimensions of the object). Thus, the coupling of a fixed and PTZ cameras is a search for the transformation function τ :

$$(a, b) = t(x, y).$$

Acceptable Deviations values Features $t(x, y)$, obtained in conjugation, from the "ideal" function conjugation transformation, at

In which there are no errors $\tau'(x,y)$, depend on the maximum angular value of the error, which is determined by the distance from the PTZ camera to the object to be aimed.

If a person is observed, for example, at a distance of 400 meters from a video camera, then, considering the width of the person's shoulders to be approximately half a meter, we get that the horizontal angular size of the person will be $0.5/400 \approx 0.07^\circ$, and in order to obtain an image of the face at least half the width of the video camera frame, it is impossible to make a mistake when conjugating by more than the specified angle of 0.07° . The lower the resolution of the images of objects can be obtained on the PTZ camera and the closer the object is to the point of fixing the video camera, the greater the value of error is allowed, so that the value of 0.07° can be considered the optimal error.

Under normal conditions, the interface error is more than 0.07° . Most modern rotary devices with video cameras, due to electromechanical limitations, have an irremovable error in pointing the optical axis, equal to 0.1° at each of the angles of the α , β . Therefore, in most cases, the interface error of PTZ and stationary cameras can be considered inexplicable if:

$$\Delta\tau(x, y) = \max_{(x,y)} \|\tau(x, y) - \tau'(x, y)\| < 0,1^\circ,$$

The smaller the interface error of the cameras $\Delta\tau$, the smaller the angular size of the objects from the general observation area can be compared. Figure 5.3 [38] shows the empirically established dependence of the error (numerical values of the norm difference $\|\Delta\tau\|$) on the inclination of the optical axis β_0 at the horizontal angle of view of the stationary master camera equal to 30° .

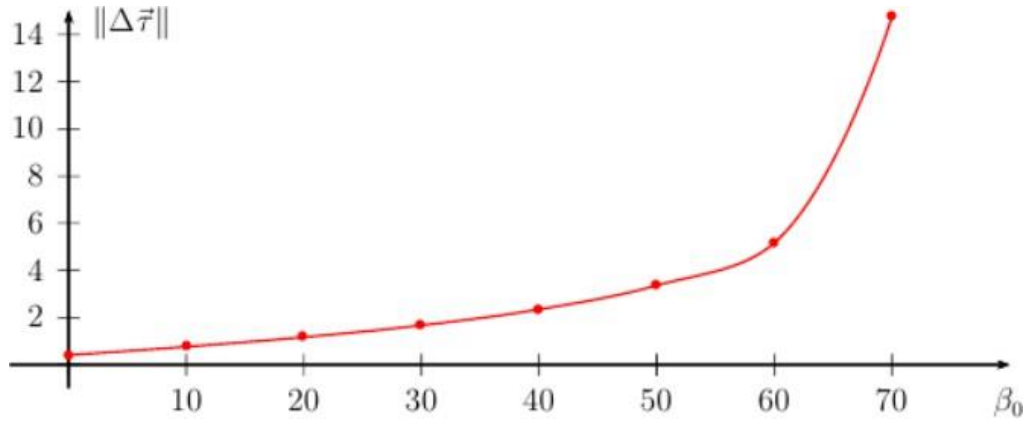


Figure 5.3 – Dependence of the error on the inclination of the optical axis β_0

From the analysis of the obtained graph, it follows that the error of the linear approximation when the cameras are paired exceeds 5° at angles $\beta_0 > 50^\circ$. The angle of 5° corresponds to the approximate linear dimensions of 4 m at a distance of 50 m from the point of attachment of the cameras. Thus, in order to obtain an image, for example, of a person by pointing a PTZ camera, it is necessary to set a magnification at which its angle of view will be at least 5° , which greatly limits the resolution of the image. On the other hand, the error of linear approximation does not exceed 2° at $\beta_0 < 30^\circ$, which is acceptable.

A statistical approach can be used to estimate the conjugation error in real observational conditions. Based on multiple repetitions of image comparison on PTZ and stationary cameras, assuming a normal distribution of deviations of the actual values of the interface transformations from the theoretical calculated values, it is possible to estimate the current level of significance by simply calculating the ratio of "misses" and "hits". At the same time, it is necessary to determine which deviation in absolute terms corresponds to a "miss".

The generally accepted definition of error is a triple variance in the distribution of deviations of the actual value from the calculated value, so knowing the value corresponding to the separation of misses and hits and the level of significance that corresponds to this value, we will be able to determine the variance, and therefore the error. If vertical leaning is β performed without "misses", the horizontal targeting estimate will be determined by the expression:

$$|\Delta\alpha| = 3 \cdot \frac{5^\circ}{F-1} \quad (1-2)$$

where $F-1(p)$ is an error function for which:

$$F(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^t e^{-\frac{x^2}{2}} dx - \text{distribution function,}$$

$$p = P(|\Delta\alpha| > 5^\circ) = P(\Delta\alpha < -5^\circ) + P(\Delta\alpha > 5^\circ) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\frac{5^\circ}{\sigma}} e^{-\frac{x^2}{2}} dx + \frac{1}{\sqrt{2\pi}} \int_{\frac{5^\circ}{\sigma}}^{+\infty} e^{-\frac{x^2}{2}} dx = 2 \frac{1}{\sqrt{2\pi}} \int_{\frac{5^\circ}{\sigma}}^{+\infty} e^{-\frac{x^2}{2}} dx = 2 - 2F\left(\frac{5^\circ}{\sigma}\right),$$

where σ is the variance of deviations $\Delta\alpha$.

The synchronization of object position data between the image processors of the stationary camera and the software control modules of the PTZ camera also affects the accuracy of aiming at moving objects and the reliability of the comparison of data about objects: if there is a delay in data exchange between video signal processors that analyze data about the object synchronized from different cameras, the probability of correct identification of identity is reduced.

The required synchronization speed is determined by the speed of the object's movement. However, there is a synchronization time, which is no longer advisable to reduce. With a processing rate of 25-30 frames per second (this is how much conventional video cameras transmit), it makes no sense to achieve a synchronization time less than $1/30 \text{ sec} \approx 3 \cdot 10^{-2} \text{ sec}$, since the object data is still updated at a frequency equal to the frame analysis rate of the video stream.

On the other hand, synchronization delays also contribute to the value of the object position prediction time, which is the sum of the camera rotation time when pointing at the object and the synchronization delay time. Thus, the greater the delay, the longer the time of extrapolation of the object's position relative to the current one, the greater the extrapolation error.

Camera rotation time is measured in values from 0.1 s to several seconds, so the synchronization time should not exceed tenths of a second, if possible, so as not to contribute to the error compared to the error that the camera rotation time makes on the object.

In a comprehensive accuracy analysis of the PTZ camera control system, in addition to assessing the speed of synchronization algorithms, it is also necessary to take into account pointing errors due to the time parameters of PTZ camera control, as well as errors in the semantic classification of objects by categories to filter events occurring in the observation area.

ActiveDome - robotic control of PTZ cameras

The ActiveDome module in the Trassir software provides operational positioning of the PTZ camera on the object of interest. Object tracking can be carried out in two modes: manual or automatic. Any combination of overview and PTZ cameras can be used in the module's operation. This module has the following capabilities [40]:

- stable operation, regardless of the position of the overview and PTZ cameras. To configure the ActiveDome, the exact relative position of the video cameras is not required. For binding, the algorithms of the built-in calibration system are used [41];
- automatic recalculation of coordinates taking into account the degree of image magnification (zoom) and their transfer to the PTZ camera;
- an unlimited number of points on the screen where you can position the PTZ camera;
- Simple positioning of the camera with one click of the mouse or by selecting the desired area on the screen; Positioning speed is limited only by the speed of the camera;
- tracking of objects both in manual and automatic mode using SIMT and Neural Network Detector of People/Objects.

Procedure for performing work

The work is designed for 4 hours and includes the following sections:

- switching on the laboratory unit and preparing it for operation;
- connection and configuration of cameras that will be used as part of the ActiveDome module;
- Mastering Methods Settings module for robotic control of the rotary camera:

- Creating and setting up a scene to form a system of connected surveillance and PTZ cameras for video surveillance of a specific area;
- adding overview (master) and PTZ (slave) cameras to the scene, setting up the module;
- calibration and pairwise comparison of survey and PTZ cameras, construction of a grid;
- experimental study of the functionality and modes of operation of the ActiveDome module:
 - manual mode of operation;
 - automated mode of operation using the object trajectory construction module (SIMT);
- Shutdown of the laboratory unit.

I. The laboratory unit is switched on and prepared for operation in the following sequence:

- supply power to video cameras;
- Turn on the computer using the button on its front wall.
- After turning on the computer, Windows will automatically start and the pre-installed Trassir Server software will automatically start.
- if there is a hierarchical structure of the Trassir system, it is necessary to create Users for computers with the Client status on PC Server and delegate to them the rights to work with analytics via the network (see the methodology within the description of the ULC SHS)

II. Connection and configuration of cameras that will be used as part of the ActiveDome module.

To configure the ActiveDome system, it is necessary to install and configure the cameras that will be used in the operation of the ActiveDome module. The procedure for connecting and configuring IP cameras is carried out in accordance with the method described in the description of the ULK SHS based on Trassir. After placing the cameras, it is necessary to select an optics model, or calibrate the optics of PTZ cameras for their correct operation as part of the module [41].

If the camera model is in the **Select a model** drop-down menu, simply select it from the list. Otherwise:

1. Select Any Camera (Start Optics Analysis) **from the Select Model drop-down menu.**
2. Position the camera so that the resulting image contains maximum contrast areas.
3. Click the *Start button*.

The process of automatic calibration of the optics will begin (it may take several minutes). During the calibration, the camera will be aimed at various points in the scene. It is desirable that the resulting image during the analysis of the optics is free of movement and extraneous noise (rain, snow, swaying trees). When the calibration is complete, a coordinate grid will be displayed on top of the image.

III. Mastering the method of setting up a module for robotic control of a PTZ camera

Settings of the ActiveDome module for working with channels Let's consider the features of the module using overview and PTZ IP cameras. The general configuration includes several stages:

- before configuring the module, it is necessary to make sure that the selection, installation and configuration of cameras for working with the ActiveDome module were made correctly, as well as the connection to the Database was correctly configured;
- on the server, go to the **Channels** item in the settings tree, select the desired channel from the list and enable the *ActiveDome module* on the selected channel in the **Software detectors area**;
- To activate the module, in the **Channel Settings** in the **Software detectors area**, select the *Server* that will calculate the analytics.

Creating and Configuring ActiveDome Scene Settings

The main setting element in the ActiveDome module is the scene. A **scene** is a system of connected overview and PTZ cameras that provides video surveillance of a specific area. In one scene, up to 4 overview and 4 PTZ cameras can be used simultaneously in any combination, while the number of scenes themselves is unlimited. In the **Analytics Modules** menu, find the *Active Dome module* and activate it (Fig. 5.4). On the right, in the open window, find the Create new... link and click on it to create a new scene.

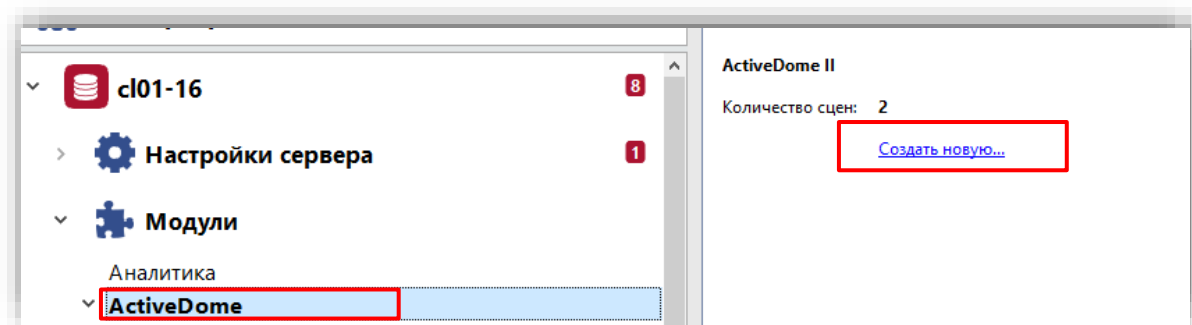


Figure 5.4 - Creating a new scene in the ActiveDome module

After clicking the **Create New ... button**, the main window for configuring a new ActiveDome scene will open (Figure 5.5).

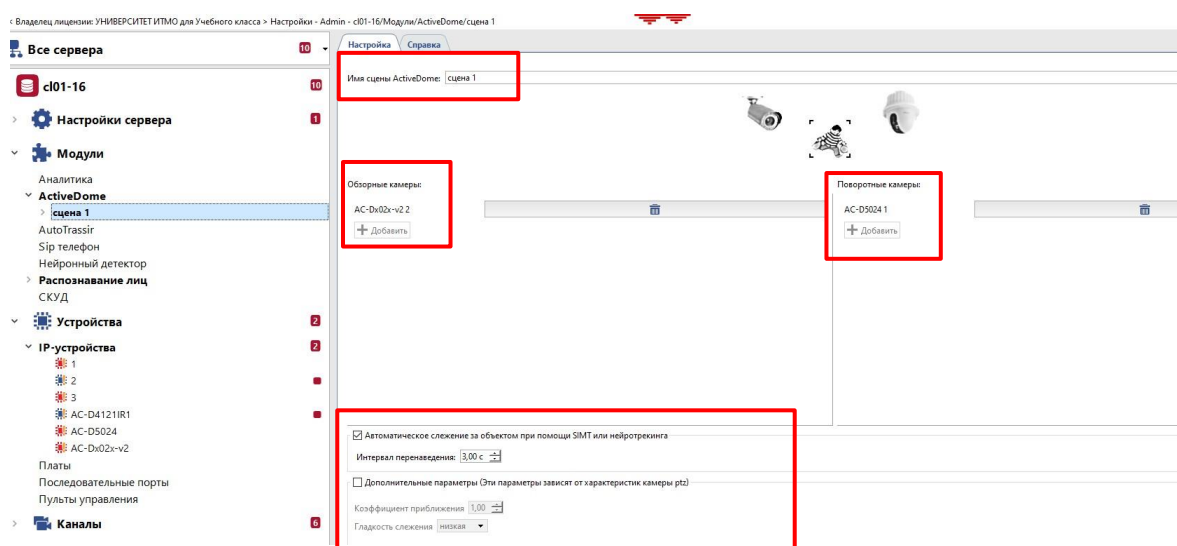


Figure 5.5 – Interface for setting up the scene

In this window, you can change the name of the scene, add overview and PTZ cameras, delete cameras or a scene. Here you can also see the settings for tracking the object in the robotic mode:

- *Automatic object tracking using SIMT or neurotracking* activates the automatic mode of ActiveDome operation ;
- The *Hover Interval parameter* sets the time after which the camera will switch to another target (if any). The range of parameter values is from 1 to 10 seconds.

Adding a Panoramic and PTZ Camera to a Scene

To do this, use the main window for setting up a new scene (Fig. 5.6)

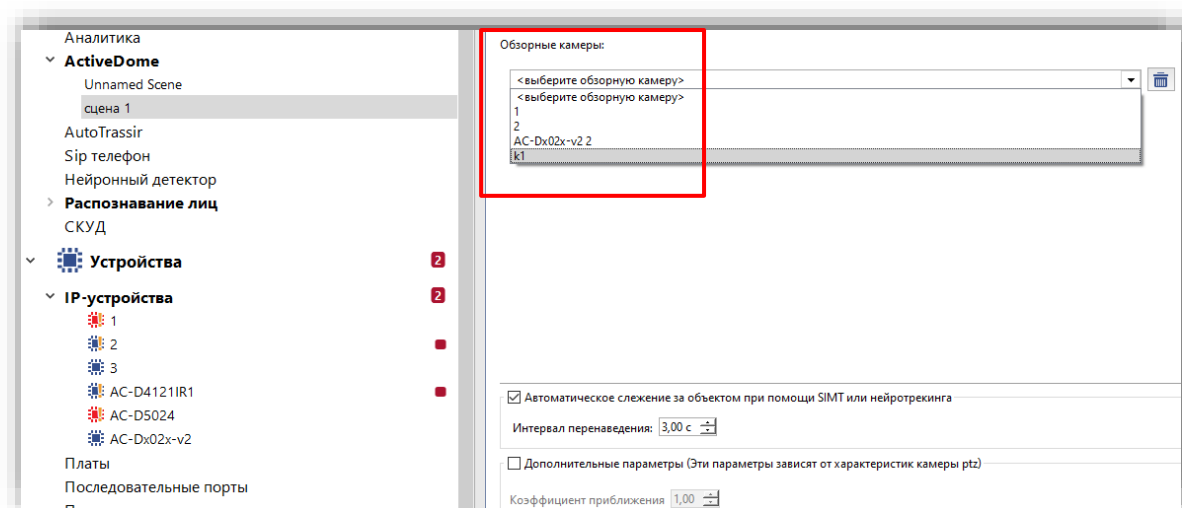


Figure 5.6 – Selection of an overview camera

In the **Overview Cameras** section, use the Add button (Fig. 5.5) to activate the drop-down list of IP devices that are currently connected to the Trassir program, select from the list and add an overview camera.

In the PTZ camera item, add a PTZ camera in the same way (Fig. 5.7).

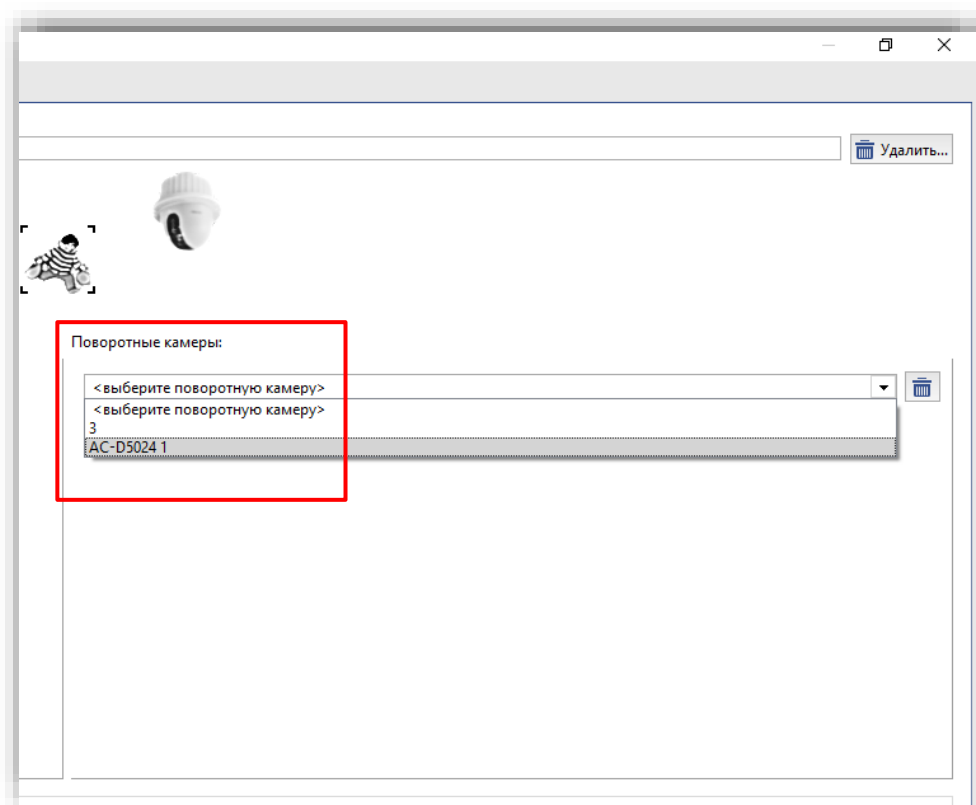


Figure 5.7 – Choosing a PTZ camera

And the automatic mode of operation of the ActiveDome module is activated by setting the flag to *the Automatic tracking of objects using SIMT or neurotracking* (Fig. 5.8). Define the value of the **Forwarding interval** parameter, which sets the time of tracking one object, after which the camera will switch to another target (in this example, 3 seconds).

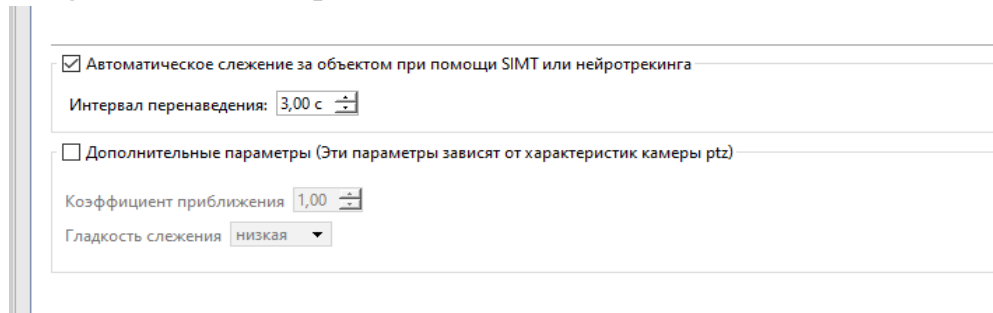
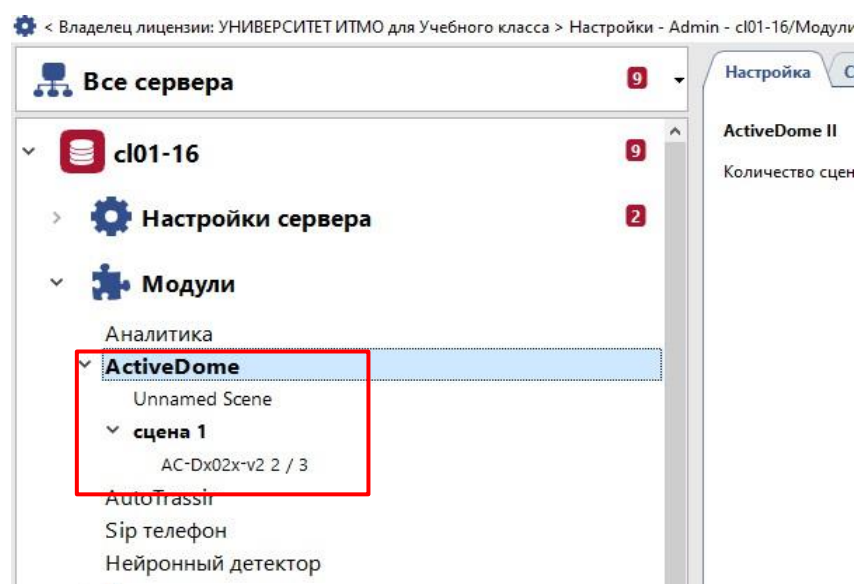


Figure 5.8 – Overview of advanced settings

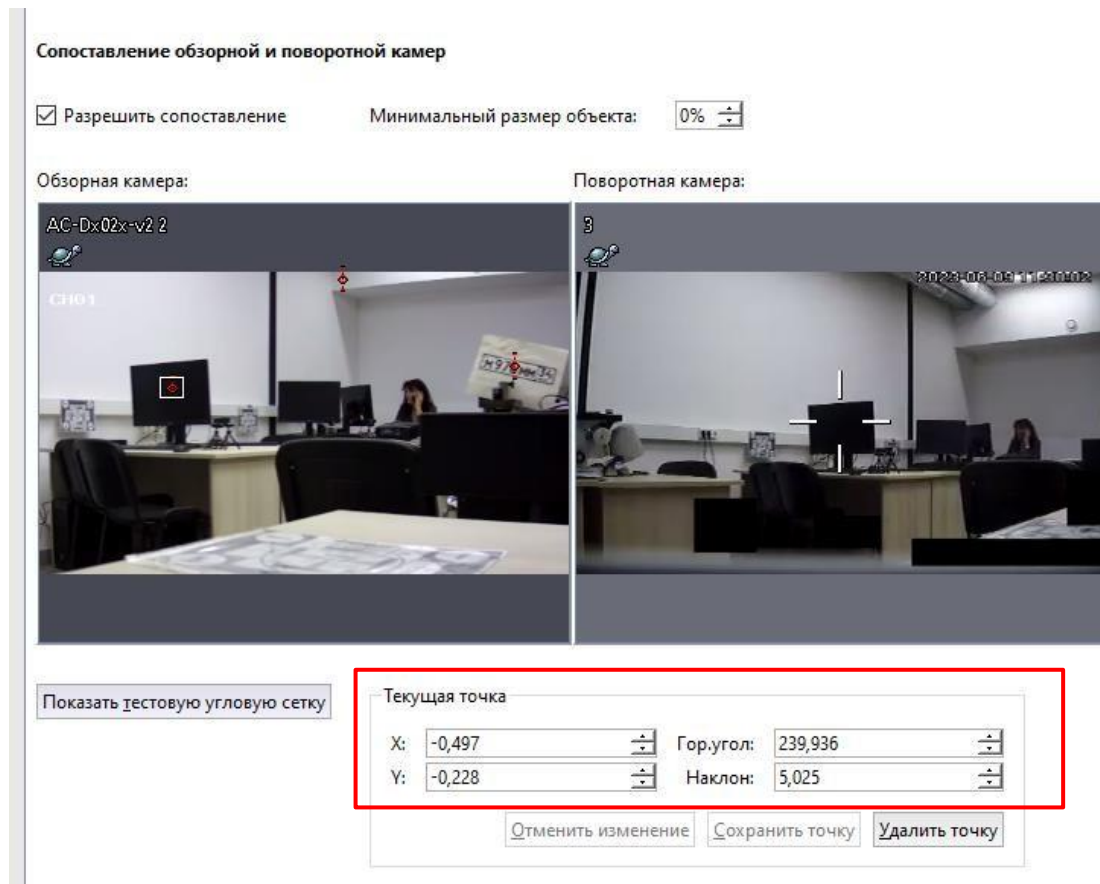
Mapping of Overview and PTZ Cameras

Next, you need to compare the overview and PTZ cameras in pairs. To do this, **open the drop-down menu** on the Active Dome module tab. Click on the arrow next to the scene that we have just created, in our case it is "scene 1". In the Server Settings tree, a complete list of combinations of overview and PTZ cameras is displayed, from which we select a bunch of cameras to be compared. The added link for our example with scene 1 will look like this (fig. 5.9):

Figure 5.9 – Searching the Camera Menu for Matching



After activating the selected pair of cameras, a window opens containing images from the overview and PTZ cameras and a menu for adjusting the parameters of their comparison with each other (Fig. 5.10). On the screen of the overview camera (master), it is necessary to manually create control (calibration) points, to which we will sequentially point the PTZ camera. An example of a control point icon is marked with a white rectangle in the image on the left in Figure 5.10.



add

several points, setting their correspondence to overview and PTZ cameras. To do this:

- In the Overview Camera window, double-click to set a calibration point.
- Set the PTZ camera lens in such a way that the crosshair points exactly to the point marked in the camera window; to do this, you can use the joystick, or fix the angular and linear (X , Y) coordinates of the crosshair in the **Current point submenu** through the camera mapping interface;
- click the *Save Point button*.

The *X* and *Y options* allow you to move a point on the overview camera screen with greater precision. The *Mountain Angle* and *Tilt* options allow you to position the PTZ camera more accurately.

After you have finished configuring the mapping of the survey and PTZ cameras, you can make a visual check for gross calibration errors by clicking *the Show Test Corner Grid button* (Figures 5.11, 5.12 – grid in the image from the overview camera on the left).

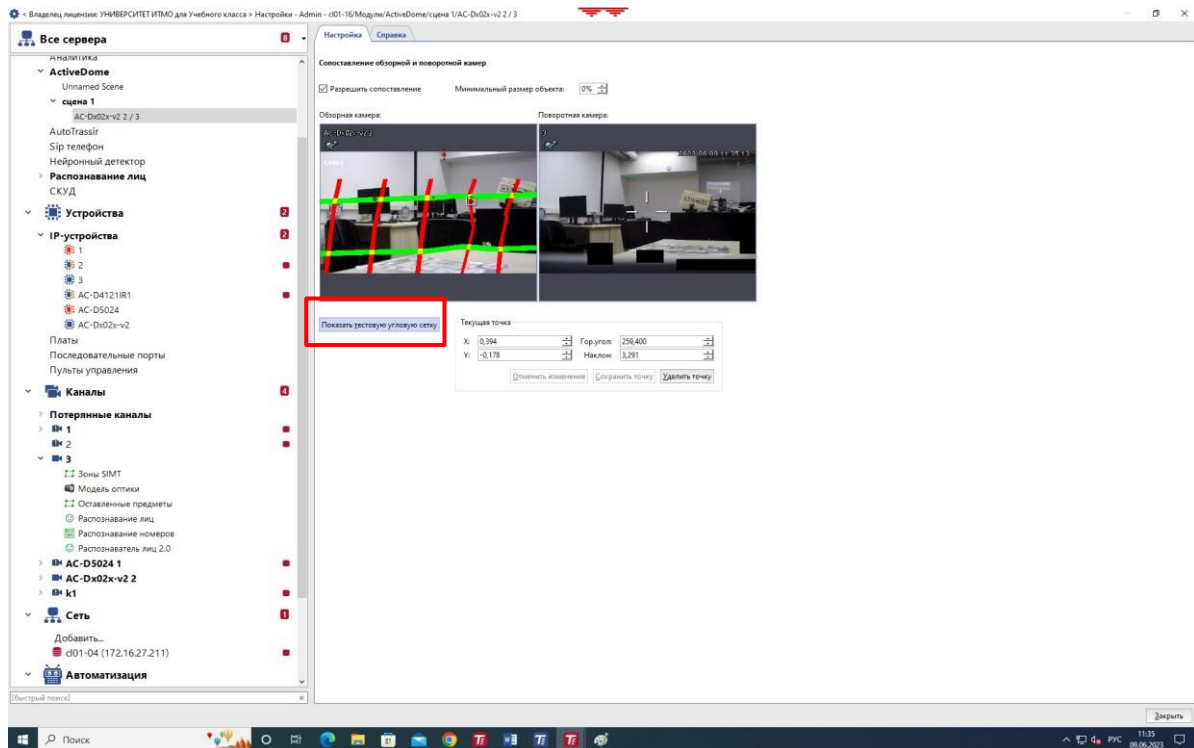


Figure 5.11 - Demonstration of the Camera Mapping Setup Window This sets the calibration points on both images to build a grid and correctly orient the PTZ camera from the image from the overview camera.

If the Required Zoom *parameter is set in the camera mapping interface* (depending on the current software license), it is possible to set the zoom value of the optical zoom of the PTZ camera lens at the marked point.

Next, it is necessary to experimentally test the positioning of the PTZ camera in different areas. If the camera is not positioned accurately, then an additional calibration point must be created in this area. For example, a more precise adjustment may be required if the overview camera and the PTZ camera are at a considerable distance from each other.

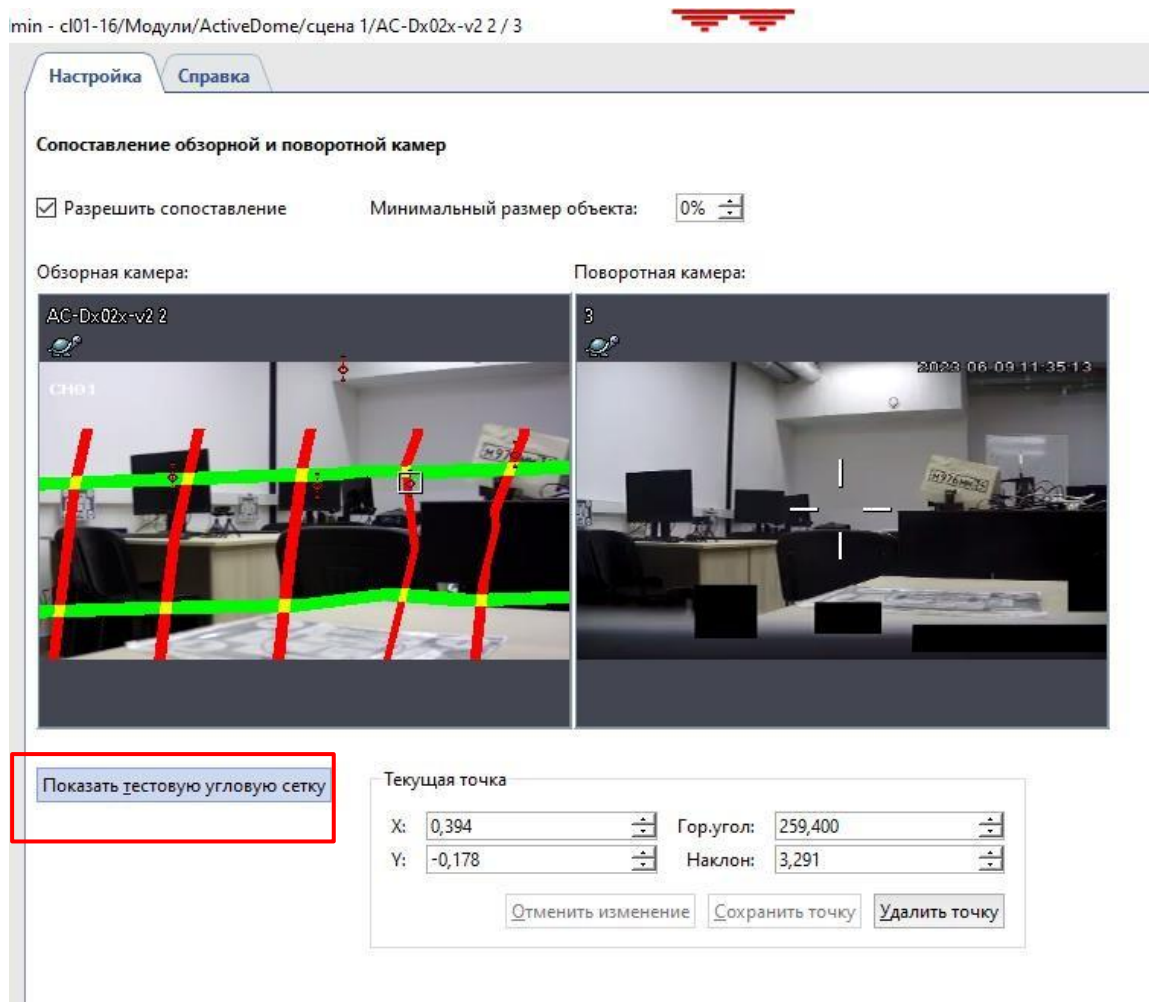


Figure 5.12 – Demonstration of the control points and the image grid

5.13 shows examples of the correct grid (left) and Meshes c abrupt kinks lines (right), that testify about a gross mistake made.

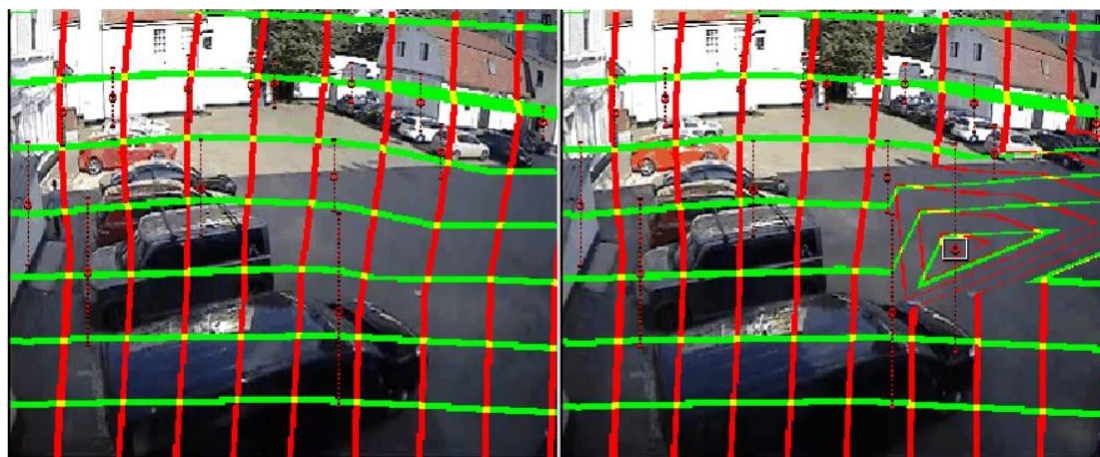


Figure 5.13 – Examples of a correct mesh and a mesh with line breaks

It has been empirically proven that for the module to work acceptably, it is necessary to set at least 3 calibration points. It should also be borne in mind that if the cameras will work in a complex geometric environment, for example, if the lens of the overview camera simultaneously captures the ceiling and three walls of the room, then it is advisable to calibrate on each of the planes. In this case, the algorithm will build a more detailed grid that will correctly describe the surrounding scene, and pointing the PTZ camera at the object will be more accurate.

IV. Experimental study of the ActiveDome module

The ActiveDome module supports manual or automatic control of the PTZ camera and its pointing at the object detected in the image from the overview camera. The choice of the mode by the operator depends on the conditions of observation of the scene, its dynamics, saturation with video monitoring objects, as well as the presence of other video analysis modules in the software license. Both modes require all the above presets related to matching (pairing), calibration, and meshing on the image.

Manual Mode Investigation

In **manual mode**, the operator highlights the object of interest in the image received from the overview video camera, which leads to pointing the PTZ camera at this object, and if necessary, the calculated scale for the image is set. In manual mode, ActiveDome can be successfully used where the movement is massive and the operator's attention is constantly required: squares, railway stations, airports, large shopping centers, etc.

There are two ways to control camera aiming in manual mode:

1. by a simple click of the "mouse" – the selected place on the screen will be displayed in the desired scale (Fig. 5.14);
2. by selecting a rectangular area on the image of the overview camera - the selected zone in this case will be displayed on the full screen (Fig. 5.15).

Thus, the operator can independently aim the PTZ camera at any field of view of the overview camera, if he wants to see something better.

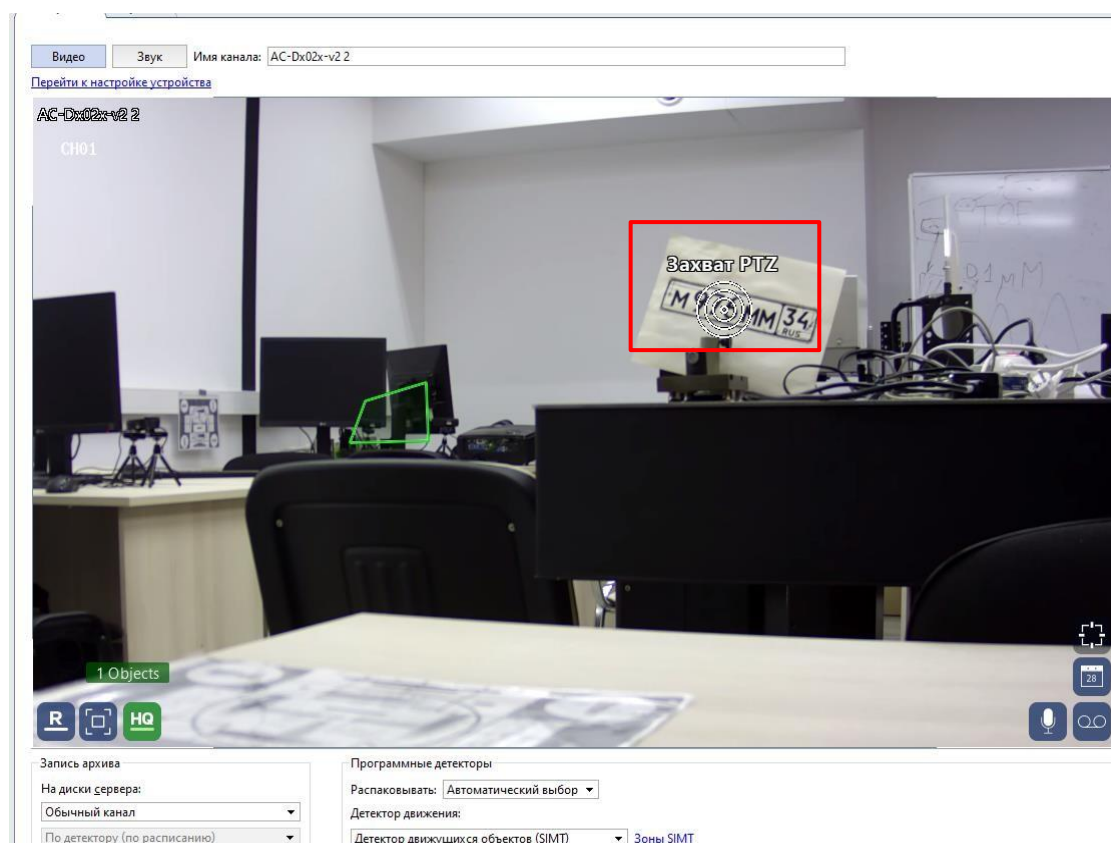


Figure 5.14 – Target acquisition by PTZ camera (white target sign on the number sheet) on the overview camera screen

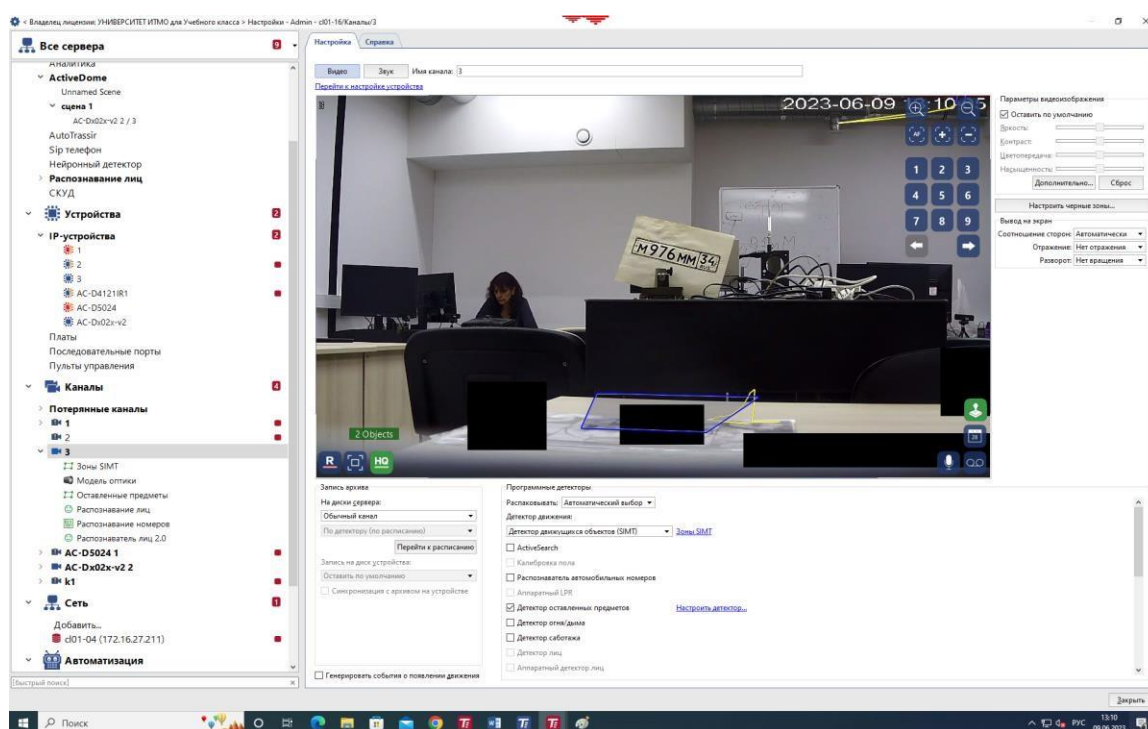


Figure 5.15 – Window for repointing the PTZ camera to the capture location of the overview camera

Study of the automatic mode of operation

The automatic ActiveDome mode can be used to protect large, sparsely populated areas where the appearance of a person or vehicle is an alarm: warehouses and surrounding areas, oil depots, military installations, bridges, railway exclusion zones, etc.

In automatic mode, information about the object for the PTZ camera can be transmitted from the motion detector or the module for building the trajectory of the the object detector and SIMT, activated on the channel of the overview camera. At the same time, the modules transmit the coordinates of objects to the ActiveDome, taking into account their predicted displacement during the camera rotation, store information about the differences between objects from each other and "remember" their history (path traveled), which allows cameras to be pointed at them in turn to register a detailed image of each object.

In this case, the video camera will switch between moving objects, accompanying them for a time called the "redirection interval". To do this, just put the flag on the item Auto tracking.... and set the redirection interval in the Scene Settings (fig. 5.16).

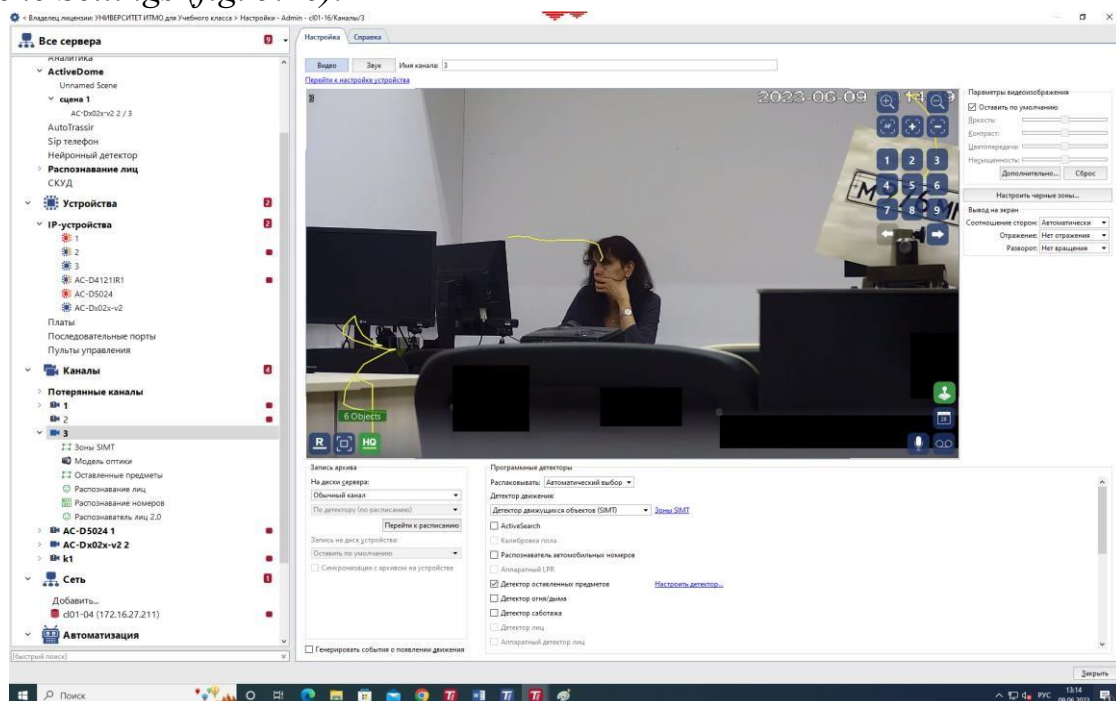


Figure 5.16 – Automatic repointing of the PTZ camera to the object of movement

Using the Web interface, we can set up and run a route for the PTZ camera to move the sight line along the

presets (presets) by which it will move, patrolling the territory. But at the moment when a survey camera with a SIMT video module detects any movement, the PTZ camera will immediately interrupt its work on the preset and point at the moving object (instructions for setting up presets for the AC-D5024 PTZ camera can be found in Laboratory Paper No6 "Study of Control Methods and Basic Modes of Operation of PTZ Drives of PTZ IP Cameras" in the manual [28]).

Note: To restart the PTZ camera in preset mode, the operator will have to do it manually!

Take and save for the report screenshots showing the sequence of your actions to study the functionality and main modes of operation of the ActiveDome module.

V. Shutdown laboratory Installations In progress
in the reverse sequence of its inclusion.

Contents of the report

1. Provides a quick overview of how to map camera images to control a PTZ camera.
2. Results Settings module in vid screenshots windows
Software with a description of the sequence of actions.
3. The results of the work in the form of screenshots of software windows and summary tables with the results of observations.
4. Brief conclusions on the work.

Control questions

1. What features and image elements are used to interface cameras in the control system? What is the purpose of the calibration grid?
2. What is the structure and functionality of the ActiveDome module in Trassir?
3. Explain the algorithm for setting the main modes of operation of the video analysis module in the Trassir system.
4. What is the effect of the grid configuration on the correct positioning of the PTZ camera relative to various image objects?
5. How do the module settings and observation conditions affect the accuracy of pointing the PTZ camera at the object of interest?

MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN
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FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"NORTH CAUCASUS FEDERAL UNIVERSITY"

SUGGESTIONS FOR TEACHING

**on the organization and conduct of independent work of
students of the direction of training**

11.03.02 Infocommunication Technologies and Communication Systems,
Specialization "Intelligent Data Processing in Infocommunication Systems and
Networks"

in the discipline "Introduction to Pattern Recognition and Machine Learning"

Stavropol, 2026

Methodical Directions by Organizations independent

students' work is compiled in accordance with the requirements of the program of the discipline "Introduction to Pattern Recognition and Machine Learning" for bachelors of the field of study 11.03.02 Infocommunication Technologies and Communication Systems. The textbook is devoted to the planned educational work of students, performed in extracurricular (classroom) time on the assignment and under the methodological guidance of the teacher, but without his direct participation, with the partial, direct participation of the teacher.

Compiler: Bratchenko N.Yu.

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8. Educational, methodological and information support of the discipline

1. Independent work as the most important form of the educational process

Independent work is the planned educational, research, research work of students, carried out in extracurricular (classroom) time on the assignment and under the methodological guidance of the teacher, but without his direct participation (with the partial direct participation of the teacher, leaving the leading role for the work of students).

It is necessary to familiarize yourself with the technological map of the student's independent work.

№	Section (topic) of the discipline and summary	Emerging competencies, indicators	Full-time			Independent work, hours	Current Forms control Academic Performance
			Contact work of students with the teacher / of them in the form of practical training, hours				
			Lectures	Laboratory work	Practical exercises		
1	Modern systems of computer modeling of technical objects 1.1. Basic concepts and composition of the computer modeling system 1.2. Levels (hierarchy) of the computer modeling system 1.3. System Engineering Modeling of Computer Vision Systems 1.4. Quality criteria of the product being developed 1.5. Generalized algorithm of the process of computer modeling of a technical object Practical lesson: Investigation of the error in measuring the coordinates of point objects at linear displacements	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	2,00	10,00	Solving practical problems
2	Methods of Modeling Technical Systems 2.1. General information about modeling technical devices 2.2. Types of models of technical systems 2.3. Main types of mathematical models 2.4. Computer Modeling at the Stage of System Engineering Design of Optoelectronic Devices	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	4,00/4,00	10,00	Solving practical problems

	Practical lesson: Investigation of the error in measuring the coordinates of point objects at linear displacements						
3	Basic concepts of computer simulation of computer vision systems 3.1. Trends in the development of computer vision systems 3.2. Analytical review of worldview concepts of computer modeling of technical systems 3.2.1. Epistemological aspects of modeling 3.2.2. Mathematical modeling of technical systems 3.2.3. Mathematical description of the modeling object 3.2.4. Simulation modeling. 3.3. Basic principles of computer simulation of computer vision systems Practical lesson: Investigation of the non-uniformity of the sensitivity of a matrix photodetector	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	4,00/4,00	10,00	Solving practical problems
4	Introduction to the Theoretical Foundations of Methods of Mathematical Modeling of Computer Vision Systems 4.1. Description of two-dimensional continuous images 4.2. Fundamentals of the Theory of Linear Filtering of Imaging Systems 4.3. Image correlation analysis 4.4. Image noise 4.5. Representation of images in digital form Practical lesson: Study of the video module for the detection of abandoned objects	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	6,00/6,00	10,00	Solving practical problems
5	Detection and recognition of objects of observation in the image 5.1. Methods for detecting and recognizing objects in the image 5.2. Statistical Recognition Methods 5.3. Criteria for Object Detection and Recognition	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	6,00/6,00	14,00	Solving practical problems

	Practical lesson: Studying the video module for building the trajectory of objects in a video stream						
6	Selecting and analyzing related areas 6.1. Selecting Related Areas in Binary Images 6.2. Methods of segmentation of grayscale images 6.3. Correlation Algorithms for Image Processing Practical lesson: Studying the video module for building the trajectory of objects in a video stream	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	6,00/6,00	20,00	Solving practical problems
7	Image Processing and Analysis Management 1.1. Information Models 1.2. Information description of the process of search and recognition of objects of study 1.3. Formation of conditions for the operability of computer vision systems Practical lesson: Study of a robotic video control system for PTZ cameras	OPK-4 ID-3OPK-4 ID-4OPK-4 ID-5OPK-4	-	-	4,00/4,00	20,00	Solving practical problems
	Total in the 5th semester		-	-	32,00/32,00	94,00	
	Exam preparation					54,00	
	TOTAL		-	-	32,00/32,00	148,00	

Independent work of students at the university is an important type of educational and scientific activity of the student. Independent work of students plays a significant role in the rating technology of education. Education at the university includes two parts that are almost the same in volume and mutual influence - the process of learning and the process of self-learning. Therefore, the SRS should become an effective and purposeful work of the student.

The concept of modernization of Russian education defines the main tasks of vocational education - "training a qualified worker of the appropriate level and profile, competitive in the labor market, competent, responsible, fluent in his profession and oriented in related fields of activity, capable of effective work in his specialty at the level of world standards, ready for constant professional growth, social and professional mobility".

The solution of these problems is impossible without increasing the role of students' independent work on educational material, strengthening the responsibility of teachers for the development of independent work skills, for stimulating professional growth of students, fostering creative activity and initiative.

Society imposes a fairly wide list of requirements for a modern specialist, among which it is important that graduates have certain abilities and ability to independently obtain knowledge from various sources, systematize the information received, and assess a specific financial situation. The formation of such a skill occurs during the entire period of study through the participation of students in laboratory classes, the performance of control tasks and tests, the writing of term papers and graduation qualification papers. At the same time, the independent work of students plays a decisive role in the entire educational process.

The forms of independent work of students are diverse. In this discipline "Computer Vision Systems" the following are provided:

The use of the material of the educational and methodological complex of disci- Plin

At the first stage, it is necessary to familiarize yourself with the mandatory minimum content of the basic educational program for the discipline studied. Next, it is necessary to study the work program of the discipline, which considers the content of the topics of the lecture course, the relationship between the topics of lectures and laboratory classes, topics and types of independent work. For each type of independent work, certain forms of reporting are provided, presented in the curriculum for the discipline "Data Bases".

Work with literature

For the successful development of the discipline, it is necessary to independently study the presented topics according to the recommended sources of information that

are presented in the curriculum.

Independent work introduces students to scientific creativity, the search for and solution of urgent modern problems.

2. Goals and main objectives of the ACS

The leading goal of the organization and implementation of the SRS should coincide with the goal of the student's education - the preparation of a bachelor with higher education. In the organization of the SRS, an important and necessary condition is the formation of the ability to work independently to acquire knowledge, skills and the possibility of organizing educational and scientific activities.

The purpose of students' independent work is to master fundamental knowledge, professional skills and abilities in the field, experience in creative and research activities. Independent work of students contributes to the development of independence, responsibility and organization, a creative approach to solving problems of the educational and professional level.

The objectives of the SRS are:

- systematization and consolidation of the theoretical knowledge and practical skills of students;
- deepening and expanding theoretical knowledge;
- formation of skills to use regulatory, legal, reference documentation and special literature;
- development of cognitive abilities and activity of students: creative initiative, independence, responsibility and organization;
- formation of independent thinking, abilities for self-development, self-improvement and self-realization;
- development of research skills;
- the use of material collected and obtained in the course of independent studies at seminars, laboratory classes, when writing course and final qualification papers, for effective preparation for final tests and exams.

3. Types of independent work

In the educational process of a higher professional educational institution, two types of independent work are distinguished: classroom, under the guidance of a teacher, and extracurricular. The close relationship between these types of work provides for the differentiation and effectiveness of the results of its implementation and depends on the organization, content, logic of the educational process (interdisciplinary connections, promising knowledge, etc.):

Classroom independent work on the discipline is carried out in classes under the direct guidance of the teacher and on his assignment.

Extracurricular independent work is carried out by the student on the instructions of the teacher, but without his direct participation.

The main types of independent work of students without the participation of a teacher in this discipline are:

- formation and assimilation of the content of lecture notes on the basis of educational literature recommended by the lecturer, including information educational resources (electronic textbooks, electronic libraries, etc.);
- preparation for laboratory work, their design.

The main types of independent work of students with the participation of teachers are:

- ongoing consultations;
- acceptance and defense of practical works (during the implementation).
- Implementation of the course work.

4. Organisation of SSDs

The methodology for organizing students' independent work depends on the structure, nature and features of the discipline "Computer Vision Systems", the number of hours for its study, the type of tasks for students' independent work, the individual qualities of students and the conditions of educational activity.

The process of organizing students' independent work includes the following stages:

- preparatory (definition of goals, drawing up a program, preparation of methodological support, preparation of equipment);
- the main one (implementation of the program, the use of methods of information search, assimilation, processing, application, transfer of knowledge, recording of results, self-organization of the work process);
- final (assessment of the significance and analysis of the results, their systematization, assessment of the effectiveness of the program and methods of work, conclusions about the directions of labor optimization).

Students' Activities for the Formation and Development of Skills of Educational Independent Work

In the process of independent work, the student acquires the skills of self-organization, self-control, self-management, self-reflection and becomes an active independent subject of educational activity.

Performing independent work under the supervision of a teacher, the student must:
master the minimum content submitted for independent work of students and proposed by the teacher in accordance with the educational standards of higher education;

□ plan independent work in accordance with the schedule of independent work proposed by the teacher;

– the student must carry out independent work in the organizational forms provided for by the curriculum and the teacher's work program;

– perform independent work and report on its results to
in accordance with the schedule for the presentation of results, types and terms of reporting on students' independent work.

A student can:

in addition to the one proposed by the teacher (with justification and agreement with him) and the minimum mandatory content determined by the program for this discipline:

– independently determine the level (depth) of the study of the content of the material;

□ suggest topics and questions for self-study;

– within the framework of the general schedule for the performance of independent work, offer a reasonable individual schedule for the implementation and reporting on the results of independent work;

– offer their own options for organizational forms of independent work;

– use for independent work methodological manuals, manuals, developments in addition to the list proposed by the teacher;

– to use not only control, but also self-control of the results of independent work in accordance with the methods of self-control proposed by the teacher or chosen independently.

Independent work of students should have an important impact on the formation of the personality of the future bachelor, it is planned by the student independently. Each student independently determines the mode of his work and the degree of work spent on mastering the educational content in each discipline. He performs extracurricular work according to a personal individual plan, depending on his preparation, time and other conditions.

5. General recommendations for the organization of independent work

The main form of independent work of a student is the study of lecture notes, their supplementation, recommended literature, active participation in laboratory classes. But for successful educational activity, its intensification, it is necessary to take into account the following subjective factors:

1. Knowledge of school program material, the presence of a solid system of gaps necessary for mastering the main university courses. This is especially important for mathematical disciplines. It is necessary to distinguish gaps in knowledge that make it difficult to assimilate new material from small abilities. By spending effort to overcome these gaps, the student will ensure normal academic performance and believe in his abilities.

2. Availability of skills, skills of mental work:

- a) the ability to take notes at lectures and when working with a book;
- b) mastery of logical operations: comparison, analysis, synthesis, generalization, definition of concepts, rules of systematization and classification.

3. The specifics of cognitive mental processes: attention, memory, speech, observation, intelligence and thinking. Poor development of each of them becomes a serious obstacle in learning.

4. Good working capacity, which is ensured by a normal physical condition. After all, serious learning is a large, versatile and diverse work. The result of learning is evaluated not by the amount of information communicated, but by the quality of its assimilation, the ability to use it and the development of one's ability to further independent education.

5. Correspondence of the chosen activity, profession to individual abilities. It is necessary to develop the ability to self-regulate one's emotional state and eliminate circumstances that disturb the business mood, interfere with the planned work.

6. Mastering the optimal style of work that ensures success in activity. Alternating work and breaks in work, rest periods, individually justified sleep duration, preference for evening or morning classes, stress resistance to exams and features of preparation for them,

7. The level of requirements for oneself, determined by the existing self-esteem. Adequate assessment of knowledge, advantages, disadvantages is an important component of the self-organization of a person, without it it is impossible to successfully manage one's behavior and activity.

One of the main features of education in higher education is that constant external control is replaced by self-control, and the active role in learning belongs not so much to the teacher as to the student.

Knowing the basic methods of scientific organization of mental work, it is possible to achieve the best results with the least expenditure of time, money and labor efforts.

The effectiveness of assimilation of incoming information depends on the ability of a person to work at a particular moment of his activity.

Working capacity is the ability of a person to work with a high degree of intensity for a certain time. There are internal and external factors of working capacity.

Internal factors of working capacity include intellectual characteristics, will, and state of health.

External:

- organization of the workplace, work and rest schedule;
- the level of labor organization - the ability to obtain information and use information;
- the amount of mental load.

The outstanding Russian physiologist N. E. Vvedensky identified the following conditions for the productivity of mental activity:

- every work must be entered into gradually;
- dimensionality and rhythm of work. Different people have a more or less different pace of work;
- the usual sequence and systematicity of activity;
- correct alternation of work and rest.

Rest does not necessarily imply complete inaction on the part of a person, it can be achieved by a simple change of business. During the day, the ability to work changes. The most fruitful time is the *morning time* (from 8 to 14 hours), and the maximum working capacity falls on the period from 10 to 13 hours, then *the afternoon* (from 16 to 19 hours) and *the evening* (from 20 to 24 hours). It is better to study very difficult material at the beginning of each period of time (preferably in the morning) after a good rest. After 1-1.5 hours, breaks of 10 - 15 minutes are needed, after 3 - 4 hours of work, the rest should be long - about an hour.

An integral part of the scientific organization of mental labor is the mastery of the technique of mental labor.

The time available to the student to complete the curriculum consists of two components: one of them is classroom work at the university according to the schedule of classes, the other is extracurricular independent work. Tasks and materials for independent work are given during training sessions according to the schedule, in the same classes the teacher controls independent work, and also assists students in the correct organization of work.

Self-study will require intensive mental work, which must not only be properly organized, but also stimulated. At the same time, it is very important to be able to maintain a steady attention to the material being studied. The development of attention requires significant volitional efforts. That is why, if a student notices that he is often distracted during self-study, he needs to force himself to concentrate. Such a procedure must be done constantly, as this is attention training. Sustained attention appears when a person treats the matter with interest.

It is necessary to properly organize your classes in time: 50 minutes - work, 5-10 minutes - break; after 3 hours of work, a break - 20-25 minutes. Otherwise, the growing fatigue will lead to instability of attention. A very important

Systematic physical education is a factor influencing the increase in mental performance. The organization of active recreation provides for the alternation of mental and physical activity, which fully restores a person's working capacity.

6. Independent work of a student is a necessary link in the formation of Researcher's Work

The progress of science and technology, information technology leads to a significant increase in scientific information, which imposes higher requirements not

only on the moral and ethical qualities of a person, but also, in particular, constantly increasing requirements in the field of education - renewal, modernization of general and professional knowledge, skills of a specialist.

Any education should act as a dynamic process that exists in a person and continues throughout his life. Mastering scientific thought and the language of science is a necessary component in the self-organization of a future research specialist. This is understood not so much as the accumulation of knowledge, but the mastery of scientifically based ways of acquiring it. This, generally speaking, is the main task of a university.

The specificity of the university educational process, in the organization of which more and more space is given to the independent work of the student, is that it seems to be the last and most adequate link for the implementation of this task. For during the study at the university, the development of the style and skills of educational (cognitive) activity takes place, the rational nature of which will contribute to the constant renewal of the knowledge of a highly qualified university graduate.

However, there are certain difficulties before this path, in particular, the transition of the student from the synthetic process of learning in secondary school to the analytical one in higher school. This is due to both the new content of education (expansion of general education and deepening of professional training) and new, hitherto unknown forms of learning (lectures, seminars, laboratory classes, etc.). The student not only acquires the knowledge provided by the program and teaching aids, but he must also become acquainted with the ways of acquiring knowledge in such a way as to be able to assess what we know, how we know it and how we have achieved this knowledge. All this is achieved through one's own independent work.

This is also because self-acquired knowledge is more operational, it becomes personal property, as well as a motive for behavior, develops intellectual traits, attention, observation, criticality, and the ability to evaluate. The role of the teacher is mainly to help accumulate knowledge (in relation to first-year students), and in the subsequent years of study, in the senior years, to jointly identify problems and take care of the student's independent search, as well as to control their activities. It should be noted that it is not possible to limit oneself only to the acquisition of knowledge provided for by the program of the discipline being studied, it is necessary to constantly deepen the knowledge gained, focusing it on some narrow defined area that corresponds to the interests of the student. In-depth study of all subjects provided for by the program is possible in practice, and good organization of work saves time, which creates conditions for a deep, systematic, interested study of the topic independently chosen by the student.

Of course, all the advice, examples, recommendations in this area, given by the teacher, or by certain publications, or other sources, do not guarantee any success without the manifestation of one's own activity in this matter, i.e. they do not give ready-made recipes, but should contribute to the analysis of one's own work, its goals,

and organization in accordance with individual characteristics. Taking into account personal capabilities, existing living and working conditions, skills, on the basis of these recommendations, it is possible to develop an individually justified set of methods, ways, find one's own style or improve it, in order to study certain material, have time to assess its significance, suitability and possibilities of its application, in order to ultimately ensure the success of one's studies from future professional activity.

7. Methodological recommendations for students on individual forms of independent work

The system of higher education implies a much greater independence of students in planning and organizing their activities.

Work with literature

When working with literature, it is necessary to select literature, learn how to read it correctly, and keep notes. For the selection of literature in the library, alphabetical and systematic catalogs are used.

It is important to remember that rational skills of working with a book are always a great saving of time and effort.

The correct selection of textbooks is recommended by the teacher who reads the lecture course. The necessary literature can also be indicated in the methodological developments for this course.

When studying the material from the textbook, one should move on to the next question only after the previous one has been correctly understood, describing on paper all the calculations and calculations (including those that are omitted in the textbook or given in the lecture for independent conclusion).

In the study of any discipline, independent individual work plays a large and important role.

Particular attention should be paid to the definition of the basic concepts of the course. The student should analyze in detail the examples that explain such definitions, and be able to build similar examples independently. It is necessary to achieve an accurate idea of what you are studying. It is useful to make reference notes. When studying the material from the textbook, it is useful to supplement the lecture notes in the notebook (in specially designated margins). There you should also note the questions selected by the student for consultation with the teacher.

It is recommended to highlight the conclusions obtained as a result of the study in the notes so that they are better remembered when rereading the notes.

Experience shows that many students are helped by compiling a list of reference signals containing the most important and most frequently used formulas and concepts. Such a sheet helps to memorize formulas, the main provisions of the lecture, and can also serve as a permanent reference for the student. There are two types of reading: primary and secondary. *Primary reading* is attentive, unhurried

reading, in which you can dwell on difficult places. may not always be understood after the initial reading.

The task of *secondary* reading is the complete assimilation of the meaning of the whole (this reading may not be the second, but the third or fourth).

Reading a scientific text is a part of cognitive activity. Its purpose is to extract the necessary information from the text. The effectiveness of the action largely depends on how conscious the reader is of his own internal attitude when referring to the word (to find the necessary information, to assimilate the information in whole or in part, to critically analyze the material, etc.).

There are four main attitudes in reading a scientific text:

1. information retrieval (the task is to find, highlight the information sought)
2. assimilative (the reader's efforts are aimed at understanding and remembering as fully as possible both the information presented by the author and the entire logic of his reasoning)
3. analytical-critical (the reader seeks to critically comprehend the material, analyzing it, determining his attitude to it)
4. creative (creates in the reader a readiness in one form or another – as a starting point for his reasoning, as an image for action by analogy, etc. – to use the author's judgments, the course of his thoughts, the result of observation, the developed methodology, to supplement them, to subject them to a new check).

The existence of several types of reading ***is associated with the presence of different attitudes to addressing a scientific text:***

1. bibliographic – viewing catalog cards, recommendation lists, summary lists of journals and articles for the year, etc.;
2. browsing – used to search for materials containing the necessary information, usually it is used immediately after working with references and catalogs, as a result of such viewing the reader establishes which of the sources will be used in further work;
3. introductory – implies a continuous, sufficiently detailed reading of the selected articles, chapters, individual pages, the purpose is to get acquainted with the nature of the information, to find out what issues are submitted by the author for consideration, to sort the material;
4. Studying – involves a thorough mastery of the material; In the course of such reading, the reader's trust in the author, readiness to accept the information presented, the attitude to the most complete understanding of the material is realized;
5. Analytical-critical and creative reading are two types of reading that are close to each other in that they participate in solving research problems. The first of them involves a directed critical analysis of both the information itself and the ways of its receipt and presentation by the author; the second is the search for those judgments, facts, on which or in connection with which the reader considers it necessary to express his own thoughts.

Of all the types of reading considered, the main one for students is the learning

one – it allows them to accumulate knowledge in various fields when working with educational literature. That is why this type of reading should be mastered in the first place. In addition, when mastering this type of reading, the main techniques are formed that increase the effectiveness of working with a scientific text.

The main types of systematized recording of what has been read:

1. Annotation is an extremely brief coherent description of the book (article) viewed or read, its contents, sources, nature and purpose;
2. Planning is a brief logical organization of the text, revealing the content and structure of the material being studied;
3. Thesis is a concise reproduction of the author's main statements without involving factual material;
4. Citation is a verbatim copying from the text of excerpts, extracts that most significantly reflect a particular idea of the author;
5. Note-taking is a brief and consistent presentation of the content of what has been read.

A synopsis is a complex way of presenting the content of a book or article in a logical sequence. A synopsis accumulates the previous types of notes, allows you to comprehensively cover the content of a book or article. Therefore, the ability to make a plan, theses, make extracts and other notes determines the technology of compiling a note.

Methodical recommendations for compiling a synopsis:

1. Read the text carefully. Clarify the incomprehensible words in the reference literature. When writing down, do not forget to put the reference data in the margins of the note.
2. Highlight the main thing, make a plan.
3. Briefly formulate the main points of the text, note the author's description.
4. Take notes of the material, clearly following the points of the plan. When taking notes, try to express the idea in your own words. Notes should be kept clear and clear.
5. Write down quotes correctly. When quoting, take into account the conciseness and significance of the thought.

In the text of the synopsis, it is desirable to give not only thesis statements, but also their proofs. When drawing up a synopsis, it is necessary to strive for the capacity of each sentence. The thoughts of the author of the book should be stated briefly, taking care of the style and expressiveness of the writing. The number of additional elements of the synopsis should be logically justified, the notes should be distributed in a certain sequence that corresponds to the logical structure of the work. Margins should be left for clarification and addition.

Mastering the skills of taking notes requires dedication and daily independent work from the student.

Practical exercises

It should be emphasized that only after mastering the lecture material from a certain point of view (namely, from the point of view from which it is presented at lectures) it will be consolidated in laboratory classes both as a result of discussion and analysis of the lecture material, and by performing practical tasks and tasks. Under these conditions, the student will not only learn the material well, but also learn how to apply it in practice, and will also receive an additional incentive (and this is very important) for active study of the lecture.

When performing tasks independently, it is necessary to justify each stage of the solution, based on the theoretical provisions of the course. If the student sees several ways to solve a problem (task), then it is necessary to compare them and choose the most rational one. It is useful to make a brief plan for solving the problem (task) before starting calculations. The solution of problems or examples should be presented in fractions, calculations should be arranged in a strict order, separating auxiliary calculations from the main ones. Solutions, if necessary, should be accompanied by comments, diagrams, drawings and drawings.

It should be remembered that the performance of each educational task should be carried out before the final logical answer required by the condition, and, if possible, with a conclusion. The performance of tasks of this type should be continued until the acquisition of solid skills in solving them.

Self-Test

After studying a certain topic from the notes in the notes and the textbook, as well as solving a sufficient number of relevant tasks in practical classes and independently, the student is recommended, using a sheet of reference materials, to reproduce from memory the definitions, conclusions of formulas, formulations of the main provisions and proofs.

If necessary, you need to carefully understand the material again.

Sometimes the insufficiency of assimilation of a particular issue becomes clear only when studying further material. In this case, it is necessary to go back and repeat the poorly mastered material. An important criterion for mastering theoretical material is the ability to solve problems or pass a test on the material covered. However, it should be remembered that the correct solution is

can be obtained as a result of the application of mechanically memorized formulas without understanding the essence of theoretical propositions.

Consulting

If in the process of independent work on the study of theoretical material or when performing tasks, the student has questions that cannot be solved independently, it is necessary to contact the teacher to obtain explanations or instructions from him. In his questions, the student should clearly express what he is experiencing difficulties, the nature of this difficulty. Advice should also be sought if there are doubts about the correctness of the answers to the self-test questions.

Preparation for the exam in the discipline "Introduction to Pattern Recognition and Machine Learning"

The study of many general professional and special disciplines ends with a test. Preparation for the test contributes to the consolidation, deepening and generalization of knowledge obtained in the process of study, as well as its application to solving practical problems. Preparing for it, the student eliminates the existing gaps in knowledge, deepens, systematizes and organizes his knowledge.

To pass the test, the student must fully complete the tasks of the practical work of the classes, prepare a report on each practical work and a report on the results of independent study of topics, according to the curriculum. If there are debts on the current certification in this discipline, the student can receive a grade "not passed".

Systematic preparation for classes during the semester will allow you to use the time of the exam session to systematize knowledge.

Current certification of students is carried out by teachers who conduct practical classes in the discipline in the following forms: interview during the defense of practical work with the provision of a written report. Admission to practical work occurs if students have a printed version of the report. The defense of the report takes place in the form of an interview.

8. Educational, methodological and information support of the discipline

List of basic and additional literature necessary for mastering the discipline (module)

List of basic literature:

1. Shefer, E. A.; Digital Image Processing: Textbook / E. A. Shefer. - Digital Image Processing, 2031-02-04. - Electron. dan. (1 file). - St. Petersburg : St. Petersburg State University of Industrial Technologies and Design, 2019. - 100 p. - Electronic. - The book is in the premium version of EBS IPR BOOKS. - ISBN 2227-8397, unlimited copies

2. Pismenny, G. V. Sistemy tekhnicheskikh zreniya v robotenichenike

[Technical vision systems in robotics]. Pismenny, B. B. Mikhailov, A. Y. Korneev. - Moscow: Mashinostroenie Publ., 1991. - 88 p. - (Industrial robots and flexible production systems). - References: p. 84. - ISBN 5-217-00995-0, 1 copies

3. Selyankin, V. V.; Computer vision. Analysis and processing of images Electronic resource / Selyankin V. V. : textbook. - St. Petersburg : Lan, 2019. - 152 p. - ISBN 978-5-8114-3368-1, unlimited copies

4. Selyankin, V. V.; Solving problems of computer vision: a textbook / V.V. Selyankin ; Ministry of Education and Science of the Russian Federation ; Southern Federal University ; Engineering and Technology Academy. - Taganrog : Publishing House of the Southern Federal University, 2016. - 93 p. : schemes, tabl. - <http://biblioclub.ru/>. - Bibliogr. in the book - ISBN 978-5-9275-2090-9, unlimited copies

8.1.2. List of additional literature:

1. Potapov, A. S.; Computer Vision Systems Elektronnyi resurs : Uchebno-metodicheskoe posobie po laboratornomu praktikumu [Computer vision systems] / A. S. Potapov, P.

O. Malashin. - Computer Vision Systems, 2022-10-01. - St. Petersburg: ITMO University, 2012. - 41 p. - The book is in the premium version of EBS IPR BOOKS. - ISBN 2227-8397, unlimited copies

2. Rafael, Gonzalez.; Digital Image Processing Electronic resource / Gonzalez Raphael, Woods Richard ; transl.: L. I. Rubanov, P. A. Chochia; ed. by P. A. Chochia. - Moscow : Technosphere, 2012. - 1104 p. - The book is in the premium version of EBS IPR BOOKS. - ISBN 978-5-94836-331-8, unlimited copies

3. Gonzalez, R.; Digital Image Processing: Practical Advice / R. Gonzalez, R. Woods ; transl. by P. A. Chochia ; trans. by L. I. Rubanov. - 3rd ed., ed. and add. - Moscow : Technosphere, 2012. - 1104 p. : ill., tabl., schemes. - (The World of Digital Processing). - <http://biblioclub.ru/>. - ISBN 978-5-94836-331-8, unlimited copies

List of information technologies used in the implementation of the educational process in the discipline (module), including a list of software and information

Reference systems

When giving lectures, computer equipment is used, demonstrations of presentation multimedia materials are used. In practical classes, students perform work and demonstrate the result by means of computer technology and reports in electronic form, prepared by them during the hours of independent work.

Information reference systems:

Information and reference and information and legal systems used in the study of the discipline:

- 1 Electronic Library System "University Library Online" – www.biblioclub.ru
- 2 IPRbooks Electronic Library System – <http://iprbooks.ru>
- 3 Electronic Library System Lan – <https://e.lanbook.com/>

Software:

- 1 Viola Workstation 10
- 2 Alt Workstation K
- 3 Viola "Server"
- 4 Office software package - P7-Office