Development of an Automatic System for Monitoring the Integrity of Power Cables Using Quasi-Distributed Fiber-Optic Sensors

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Abstract

The article proposes a new method for monitoring the intensity of a light wave in an optical fiber and the additional losses formed from mechanical impacts on it. The problem of violating the safety of underground power cables is identified and, a goal to develop a security system is set, methods and materials of construction are demonstrated. The results of the fiber-optic perimeter protection system development for various purposes objects, including border boundaries, are presented. The method is based on a software analysis of changes in the pixel pattern of a light spot falling on the surface of a high-resolution photomatrix, which is installed at the output of an optical fiber. The task to create a laboratory sample and software was implemented. The developed software allows to evaluation changes in the light spot intensity depending on the situation on the guarded perimeter in real-time meters and to alarm the operator when the intruder attempts to overcome the protected area. The proposed security system is energy and resource-saving since it does not use metal conductors and electrical signals. The electromagnetic influence of the power cables does not affect traveling through fiber-optic sensors light wave properties.

Keywords [1]

security system, fiber-optic sensor, unauthorized access, optical fiber, guarded perimeter

1. Introduction

The conclusion for the analysis of the district energy company Astana REC distribution networks problems is that there are cases of 0.4 kV power cables theft. Both the live cables and the backup cables were stolen. In the public domain, much information related to the theft of wires and cables, not only in the Republic of Kazakhstan but also in other former USSR countries, can be found. One method of fighting this phenomenon is the organization of cable line protection using private and departmental security structures. However, through the efforts of the police, it is impossible to reverse the situation and effectively fight this phenomenon [1]. The publication of media reports of electrical conductors' thefts The fact that the police and security agencies cannot solve this problem is confirmed by [2]. Malefactors find various ways to bypass the security alarm installed at the transformer substation. For example, arrange tunnels and penetrate the cable channel avoiding the protected areas (figure 1). The premises of transformer substations are equipped with security systems and put on round-the-clock monitoring to countermeasure theft.

Nevertheless, the Astana REC company is forced to use part of its funds not for development but for the elimination of the CL theft consequences in various sections of the extensive distribution network of Astana. The electrical distribution terminals are not connected to the transformer substation

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(TS) because of the construction works. Therefore, due to the absence of the voltage extracting the CL from the cable channel becomes easier. Existing security alarm systems react to penetration into the premises of a TS but do not protect the cable channel from undermining [3]. In addition, the digs are carried out manually by malefactors inside the city and masked. They turn out inconspicuous and difficult to detect when security services bypass the territory. This allows criminal communities to flourish and continue their activities almost impunity [4]. The effectiveness of the measurement system alterations proves the possibility of the resource-saving measurement system [5], [6]. One of the solutions to the problem is using an automatic system for monitoring the integrity of power cables using quasi-distributed fiber-optic conductors.

Figure 1. Example of cable channel placement

The literature analysis has shown considerable interest in using OF in security systems; for example, security systems of various firms are already available and sold on the world market. The basis for the security systems is a radiation source, a fiber-optic sensor, a photodetector, and a data processing device [7,8]. There are some successful developments and leaders in this field that have been present on the market for decades. For example, Future Fibre Technologies FFT (Australia); Remsdaq (England); TRANS Security Systems and Technology (TSS) (Israel); Fiber SenSys (USA); Magal (Israel); Senstar-Stellar (Canada), NGO Applied Radiophysics "Raven" (Russia); "Danube" (Russia); "Gyurza" (Russia) [8,9]. The number of certain similarities between different security systems unites them into several groups [11-13].

The existing solutions use optical interferometer principles. The advantages of such systems are their secrecy, resistance to electromagnetic radiation, and being intrinsically safe [14-17]. In addition, it can be used for extended perimeters over 20 km [18]. Therefore, using optical fibers to construct passive perimeter and boundary protection systems for various objects is an auspicious direction [16]. The results of processing signals received from fiber-optic sensors are presented, as well as methods for normalizing the counting level of fiber-optic interferometric sensors insensitive to polarization [19]. It is necessary to consider the experience of developing a frequency fiber-optic signaling system [20, 21]. The research results presented in [22] also confirm that a sufficiently high level of interference occurs in an optical fiber when its temperature changes. Signal transmission over 100 km via fiber is not a problem, while energy costs are not comparably low compared to control cables [22,23]. The source [24] presents methods of anti-interference and ways of protecting information transmitted over optical fibers. The analysis showed certain advantages of optical fiber for its use as a sensitive element of an automatic system for monitoring the integrity of power cables. Based on optical fibers, it is possible to create distributed and quasi-distributed fiber-optic sensors for cable channel security systems. Accordingly, an important point is a search for new solutions to reduce the cost of fiber-optic signaling. To solve the tasks set, a proprietary method has been developed that allows solving this problem and creating its design of an automatic system for monitoring the integrity of power cables using quasi-distributed fiber-optic sensors.

The research aims to develop an automatic system for monitoring the integrity of power cables using quasi-distributed fiber-optic sensors. The novelty lies in developing a new method for building a security system and monitoring the technical condition of power cables, which has not been used before.

The proposed method uses a single-mode fiber loop, along which the laser beam passes in a circle and returns to the data processing unit. The high-resolution photo matrix is installed on the end of the optical fiber, on which a light spot that resembles a Poisson spot falls. It has a bright middle and a darker edge. Which is characteristic of the stepped profile of a single-mode optical fiber obeying the customary Gauss distribution law. Many scientists note that using one such fiber as a sensor is characterized by a significant amount of noise and therefore, negatively affects the stability of the control system (measurement). It can also be noted that it is quite challenging to extract information from a step profile obeying a Gaussian distribution since this is essentially noise. The difference is that a high-coherence laser with a wavelength of 650 nm with deviations up to 1% is used. Significant variations disrupt the system as a whole. To increase the coherence of the laser, a pitching current stabilizer has been specially developed, which reduces pulsations at the output of the radiation source. The image of a light spot turns into a negative and is further subjected to intelligent analysis using a Python program. When exposed to a fiber-optic sensor, a photoelastic effect occurs, accompanied by a change in the parameters of the light wave, in particular, its intensity. A photo matrix records all changes, and the program converts the magnitude of the impact into a change in the picture of pixels. The stronger the effect on the fiber-optic conductor, the higher the level of additional losses formed during micro-bending; respectively, the number of pixels changes from black to white in the same proportion.

The novelty lies in a new data processing method based on the analysis of changes in the intensity of a light spot incident on the surface of a photographic matrix. Unlike other methods, where only a single-pixel photodetector is used. For example, in the method of optical reflectometry. Also, a novelty is the transformation of a light spot from positive to negative for the analysis of additional losses arising in the optical fiber shell during mechanical action on it and the subsequent intelligent analysis of changes in the intensity of the negative. In the absence of exposure to the optical fiber, the image on the screen is a black square, but when exposed to the optical fiber, round-shaped images of white pixels appear on it. The program considers the impacts' parameters, and if they exceed the setpoints, an alarm is triggered.

2. Methods and materials

A sample of an automatic system for monitoring the integrity of power cables using quasi-distributed fiber-optic sensors is demonstrated on Figure 2. Fiber-optic conductors of the KC - OKKO - A - 2 - G.652.D - UCF and KC - FTTH - A - 2 -G.652.D – UCF brands were used as sensors. Fiber-optic conductors were laid in the cable channel from DS179 to TS 3257, 3258, and 3259. All objects are on the balance sheet of Astana REC. The protected area is divided into 4 zones. Here 1 is the Data processing Unit; 2 is channel №1; 3 is channel № 2; 4 is channel №. 3; 5 is channel №. 4, and 6 is the symbol of the cable channel.

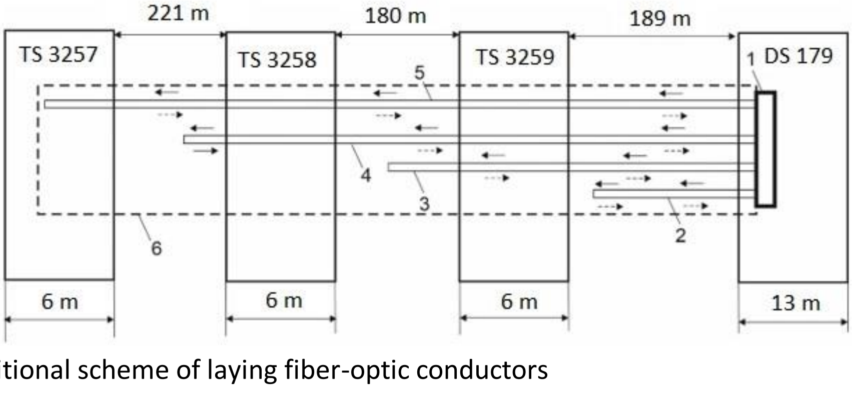


Figure 2. Conditional scheme of laying fiber-optic conductors

One channel contains two conductors, one is called direct, the second reverse. Through a direct conductor, light travels from the source to the endpoint of the channel and returns to the photodetector on the reverse. The conductors of channels 1-4 are connected to the data processing unit using optical connectors. Full-scale experiments were carried out in the conditions of a real 10/0.4 kV electrical network of the Astana REC company. Transformer substations (TS 10/0.4 kV) and a distribution point of DS 10 kV are in the "Deputy Town" area of Astana city. Figure 3 shows the installation area. The route of laying quasi-distributed fiber-optic sensors in the cable channel of the 10/0.4 kV power supply system is marked on the map.

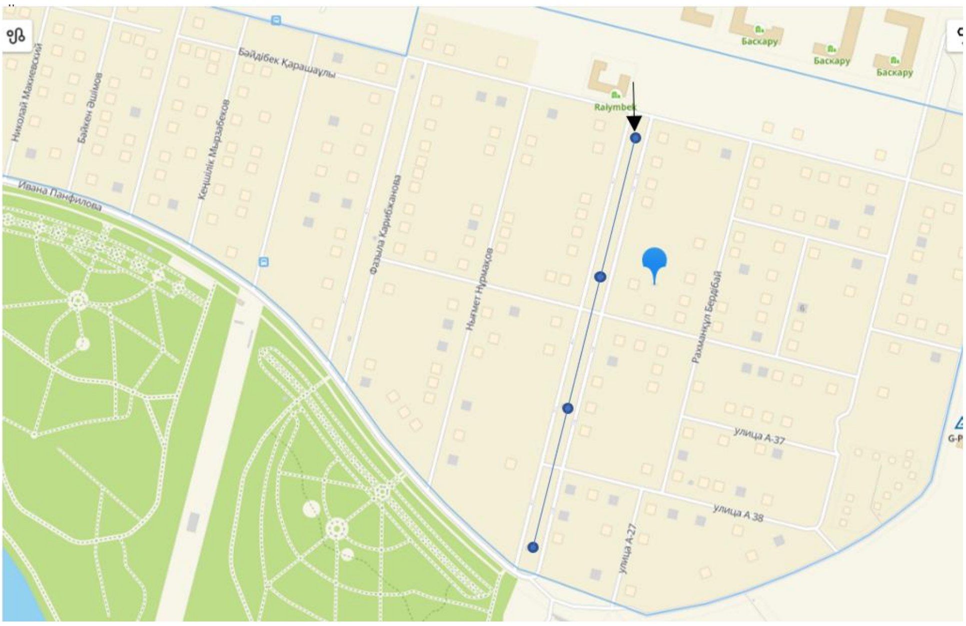


Figure 3. Map showing the location of TS 10/0.4 kV and RP 10 kV "Deputy town" Astana city

Figure 4. Photo of the street with the location of TS 10/0.4 kV

Figure 5 shows how the processing unit was installed inside the 10 kV DS room. The data processing unit is equipped with an uninterruptible power supply to ensure the reliability of the security system. When an alarm is triggered, data is transmitted via cellular communication channels using a 4G radio modem to the dispatcher's console of the Astana REC company, and there is also a server for storing information, which is made based on a personal computer. The alarm signal is also transmitted to the security service by sending messages to the Telegram messenger. The system is mounted in a universal wall cabinet Spacial CRN 800x600x300 Schneider Electric. Figure 6 shows the assembly and commissioning of an automatic system for monitoring the integrity of power cables using quasi-distributed fiber-optic sensors. The 4-channel system was assembled in the laboratory. All scheme elements are fixed on a typical metal base, subsequently integrated into a universal wall cabinet. A fiber-optic conductor of the KC - OKKO - A - 2 -G.652.D - UCF and KC - FTTH - A - 2 -G.652.D –

UCF brands were installed directly on the object itself, which have a protective plastic shell and a power element made of Kevlar thread.

Figure 5. A universal wall cabinet with a processing unit placed inside a 10 kV DS room

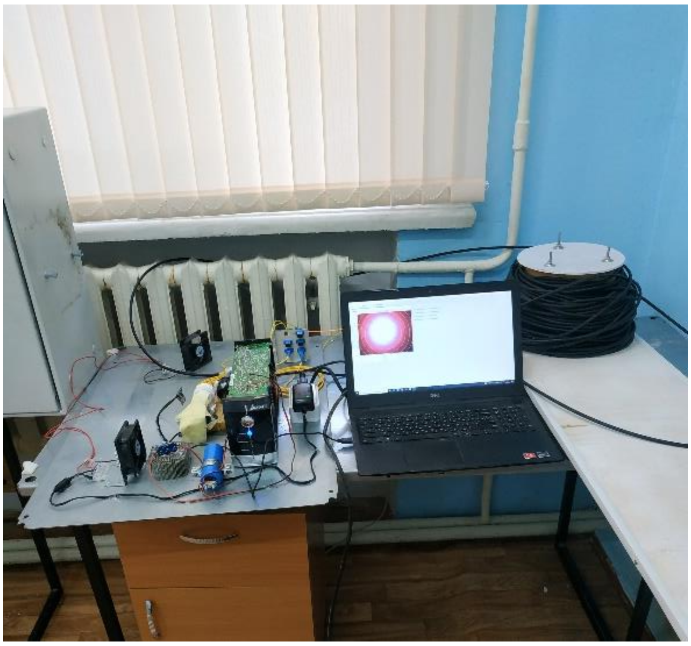


Figure 6. System assembly and configuration

Two different types of conductors were selected to compare their sensitivity in cable channel. Figure 7 demonstrates the process of installing fiber-optic conductors in a cable channel by employees of the Astana REC company. For the convenience of installation, the cable channel was opened in three places, what made possible to drag fiber-optic conductors. During the installation of the fiber-optic conductors, special care was taken to avoid breaking them and damaging the protective shell. The automatic system for monitoring the integrity of power cables with the help of quasi-distributed fiber-optic sensors, further ACCS basically does not use known methods and principles of known analogues operation [8,9]. Since there is not enough information in open sources to create an ASCC, it does not have fundamentals of the known methods and technical solutions discussed in [10-14]. An important point of practical implementation of scientific development and its use in the future, the Astana REC company has put forward the conditions for the minimum cost of one control point, as well as the simplicity of the design of the ACCS and insignificant operating costs. Figure 7 shows the process of installing fiber-optic conductors in a cable channel. It was decided not to use the well-known methods of optical interferometry and reflectometry, as well as fiber Bragg gratings. These methods have been sufficiently studied and considered in the scientific literature [15,16].

Figure 7. Installation of fiber-optic conductors

For example, the well-known optical interferometry method is due to the dependence of the light wave distribution phase on temperature since a change of 1 ° C can cause a false alarm without mechanical impacts on the sensor [8,9]. The use of optical reflectometry methods or Bragg gratings due to the higher cost of components and the need to use high-tech equipment increases the cost of ACCS [9,10]. To implement the ideas for creating a new ACCS, a spectral analysis method of a light spot falling on the surface of a high-resolution photo matrix installed at the output of a single-mode optical fiber, which is used as a sensor, was developed. During mechanical impact on the fiber-optic conductor of the ACCS, a well-known photoelastic effect occurs, which causes a change in the phase of propagation of the light wave and changes in its properties, in particular intensity. Mechanical impacts on the fiber-optic conductor led to a change in the beam path of the optical interferometer, and many ASCs are built on this principle. Still, the optical interferometer has a rather serious problem with temperature fluctuations, a change in the phase of propagation of the light wave in the OF is observed. Mechanical effects on the fiber-optic conductor of the ACCS lead to additional losses of the light mode in the OF, which can be fixed and used for the operation of the ACCS. The presence of further losses in the OF is recorded by the change in the intensity of the light spot falling on the surface of the photo matrix. The difference is using a high-resolution photo matrix and not a single-pixel photodetector. Therefore, the analysis of changes in the pattern of light spot pixels, unlike analogs, where only the amplitude of the light signal is recorded, is possible [15,16].

The development of the new method was based on the fundamental equations for light wave propagation. The intensity of the light wave I can be described by the following equation:

$$I = \langle Re\left[\left|\vec{E}(t)\right|\right] Im\left[\frac{\partial\vec{B}(t)}{\partial t}\right]\rangle\rangle \approx \frac{1}{2}\left|\vec{E}_0\right|\left|\vec{H}_0\right|, \quad (1)$$

where $Re\left[\left|\vec{E}(t)\right|\right]$ – a real part of the magnetic field strength equation; $Im\left[\frac{\partial\vec{B}(t)}{\partial t}\right]$ – imaginary part of magnetic induction vector derivative over time function; E_0 – magnetic field strength in vacuum; B_0 – magnetic induction vector in vacuum; λ_0 – wavelength in vacuum.

Equation (1) can be presented in a next way:

$$I \approx \frac{1}{2}\sqrt{\frac{\varepsilon_0\varepsilon}{\mu_0}}\vec{E}_0,$$

where ε_0 – electrical constant; ε – dielectric constant.

The distribution of the volumetric power density of the electromagnetic field of the wave at the angles α_0

$$P_{Vt}(\zeta_0; \omega; T; d; \theta; \alpha_0) = 2\omega\sqrt{\varepsilon_0 \varepsilon \mu_0} I \approx 2\omega \frac{n_\infty(\zeta_0;\omega;T;d;\theta;\alpha_0)}{\mu_0} I, \quad (2)$$

where ζ_0 – manifold that describes the behavior of the molecules, T – temperature, d – diameter of the optic fiber, θ – angle of the light spot falling.

Considering,

$$I(\alpha_0) = I_0(r) \times (\frac{sin\alpha_0}{\alpha_0})^2 \quad (3)$$

The measured values in experiments can be found using (2) and (3) by the next equation:

$$P_{Vt}(\zeta_0; \omega; T; d; \theta; \alpha_0) = 2\frac{\omega I_0(r)}{c\pi} \int_0^\pi n_\infty(\zeta_0; \omega; T; d; \theta; \alpha_0)\, d\alpha_0. \quad (4)$$

Figure 8 presents the essence of the intensity control method and additional losses. Two images of the light spot are shown, positive and negative. The theoretical foundations of this method have already been published and discussed in detail [15,16]. The spot falls on the surface of the photo matrix, a picture is formed when the core is brighter and the shell is darker since only the losses of the light wave are concentrated in it, and, accordingly, their increase can be recorded under mechanical impacts. The light spot obeys the standard Gaussian distribution and contains a significant amount of noise generated by the radiation source; software is used to level out interference [15,16].

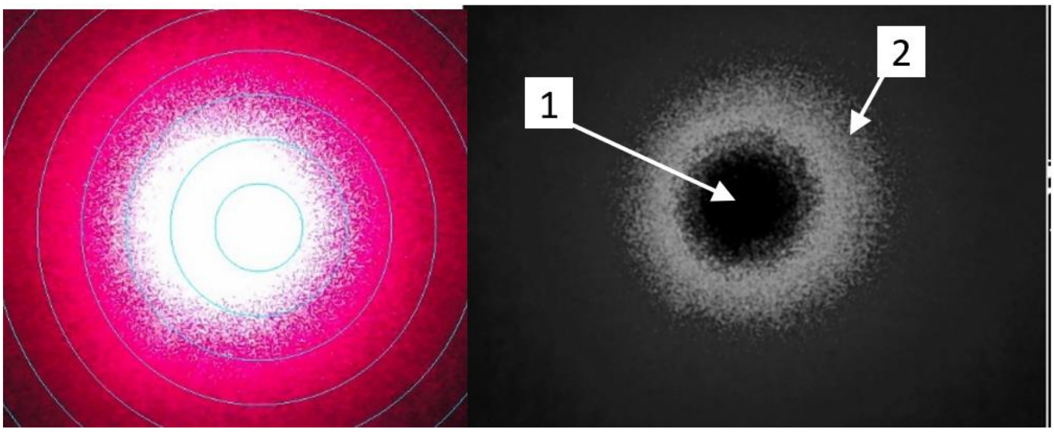


Figure 8. The shape of the light spot falling on the surface of the photo matrix. Where 1 – negative of the OF core; 2 – negative of the OF hell

The positive is not used, since the losses spread through the shell, and it is dimmer in the positive image. The core, on the contrary, is brighter but not informative; respectively, there is a brighter shell in the negative. The method is based on controlling additional losses formed in the shell. The laser should be coherent with a deviation of no more than 5 nm, and the wavelength is 650 or 850 nm. The choice of the wavelength of 850 nm is justified by the smallest attenuation of the light wave in the single-mode S compared with the visible range of 650 nm, which is desirable to use over a length of up to 10 km. The principle of operation of the proposed ACCS is based on using a light source (laser radiation), a single-mode or multimode optical fiber, and a photodetector [15, 16]. The laser is installed on one side of the OF, and the photodetector on the other. Mechanical or vibroacoustic impacts are applied to the OF to cause a change in the properties of the light wave traveling through the core, which is recorded by the photodetector. Next, the data processing and decision-making system issues an alarm, ignores the recorded changes, and recognizes random interference. When mechanically acting on a fiber-optic conductor, the pixel pattern of the light spot changes. The program converts all changes in the intensity of the light spot and increases additional losses into a picture of pixel changes. Figure 2 shows a screenshot from a computer screen, which shows several options for changing the pattern of pixels of a light spot and their transition from black to white light. The stronger the impact on the fiber-optic conductor, the greater the changes in the intensity of the light spot, and the greater the additional losses that occur propagating through the shell of the fiber-optic conductor, respectively, the greater the number of white pixels. Figure 9 presents several variants of the light spot; when interference occurs, the number of pixels increases, position 1, but their growth rate is different, and the number is smaller compared to positions 2 and 3 when the growth of white pixels is quite significant since the fiber-optic conductor was affected to simulate overcoming the guarded perimeter. The light spot is transformed by the program from the image in Figure 8 to the picture of pixel changes shown in Figure 9.

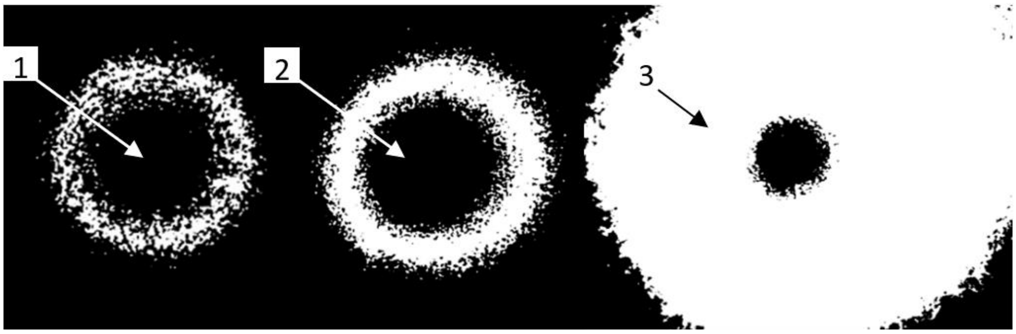


Figure 9. Computer screen shot

On the computer screen, can be clearly seen the light spot changes, especially at the interface between the core and the shell of the optical fiber. The program distinguishes between the impact on the FOS and interference, for example, changes in external temperature or wind gusts. Interference always generates a smaller number of white pixels compared to the impact of unauthorized access by the intruder when trying to overcome the guarded perimeter. The program analyzes the change in the pattern of pixels of the light spot and decides whether the alarm is triggered. If the impact has been made several times with a certain intensity and frequency, then this is perceived as an intrusion.

A more substantial impact causes a large change in the picture of pixels and provokes their transition from black to white. The system records all changes, and with several impacts exceeding the setpoint, the system is triggered. The program gradually changes its sensitivity in case of interference, which differs in frequency and rate of intensity change from the impact on the fiber-optic conductor. The method allows you to control the rates of changes in the derivative of the intensity of the light wave and time losses, as well as changes in the shape of the spot and the transition of pixels from white to black. The program can recognize noise since noise growth and mechanical impact are characteristic of different indicators of changes in the intensity of the light spot. The program also performs a numerical assessment of the pressure level on the OF when it bends. All changes in the light spot can be observed in real-time. The prototype of the automatic ACCS currently has 4 independent channels, which now is limited by the lack of need to increase the number of channels and software. Still, the number of channels will significantly increase in the future. Figure 10 shows the block diagram of the prototype ACCS. The proposed ACCS is arranged as follows: an uninterruptible DC power supply 1 is connected to a coherent semiconductor laser 2 with a wavelength of 650 nm, with a power of 10-30 MW, depending on the length of the fiber-optic conductors. To reduce interference from the radiation source, an optical polarizer and an insulator are used 3. Optical radiation is divided in the proportion of ¼ in the optical splitter 4. The channels in the diagram are indicated by position 5.

The proposed ACCS has 4 channels; in the future, the number of channels will be increased to 64. It will protect the 16 km long section, divided into separate protection zones with a length of 500 m. The protected area's size can range from 20 to 500 meters, depending on the situation and the customer's wishes. Two or more data processing units can be installed on the object if necessary. The maximum range of action is up to 20 km. The ACCS contains a laser power supply 1 that stabilizes voltage and current parameters to reduce laser pulsation, which negatively affects the system's operation and can become a source of interference. The semiconductor laser operates at a wavelength of 650, and its power is 30 MW. There are devices for matching; this is an optical polarizer with an insulator 3 and an optical splitter 4. The optical splitter divides the beam into the required number of beams, but the power is distributed equally. A fiber-optic conductor 5 in the cable channel is used simultaneously as a guide system and a sensor. The fiber-optic conductor is connected to the optical splitter 4 using standard universal UPP 2.5 mm adapters and SC 2.5 mm optical connectors. The fiber-optic conductor is placed in cable channel 6 and conditionally divided into two directions of the light wave movement, "forward" and "reverse". Previously, Figure 1 showed the directions of the light wave movement through fiber-optic conductors. The light beam passes along the entire length of the single-mode fiber-optic conductor 5 and falls on the surface of the photometric 7 mounted on its end. Each channel contains one high-resolution photo matrix. All four photometric are connected to a microprocessor-based data preprocessing device 8. Next, an electrical signal is sent through the matching device 9 to computer 11 by connecting cable 10 for final processing and issuance of a solution. As shown earlier in Figure 7, under mechanical action, the parameters of the light wave passing through the core of a single-mode fiber-optic conductor 5 change, which the ACCS fixes.

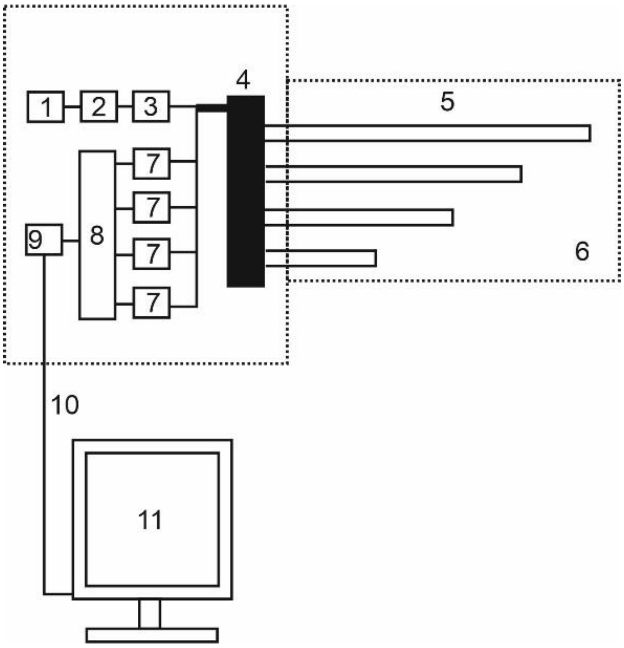


Figure 10. Structural diagram of the laboratory sample of the ACCS. Where 1 – laser power supply; 2 – semiconductor laser with a wavelength of 650 or 850 nm; 3 – optical polarizer with an insulator; 4 – optical coupler; optical fiber input and output device (cross); 5 – single-mode fiber-optic conductor (G652 sensor); 6 – cable channel; 7 – photodetector; 8 – data preprocessing device; 9 – matching device; 10 – connecting cable; 11 – a computer with software.

3. Results

The result is the development of a prototype of an automatic perimeter security system using fiber-optic conductors and software. The software is an important part, as it is the basis of the proposed method of intelligent pixel analysis of the light spot and the determination of additional losses in OF. The program is written using the Python programming language. Figure 11 shows all the options for the operation of the automated control system in various modes when exposed to a fiber-optic conductor and without exposure.

When the "yellow" or "red" indicator is turned on, the system automatically saves the trigger time in the computer's memory. The program window can be divided into three main parts, from the left, the settings block, and from the right, the scale for assessing the level of impact on the FOS and the number of impacts over a certain period. In the lower part, there are indicators: green "normal mode,» yellow "probability of intrusion" (warning), and red "alarm.» Each of the four zones has a length of 500 meters. While the prototype of the ACCS works with a length of channels at most 1 km. Increasing the number of protected areas and the distance is not difficult and can be easily implemented. The maximum size of the protected perimeter for one data processing unit developed by ACCS is up to 20 km.

When an alarm is given, the ACCS sends messages via cellular communication channels to authorize persons for decision-making. The study was carried out using a method for measuring additional losses during mechanical action and bending formation on an optical fiber. The method is based on changing the properties of light emitted from a laser radiation source. The laser radiation source is a laser diode with a wavelength of 650 nm with a power of 30 MW, the principle of operation of which is based on the occurrence of a change in population in the pn junction region during the injection of charge carriers.

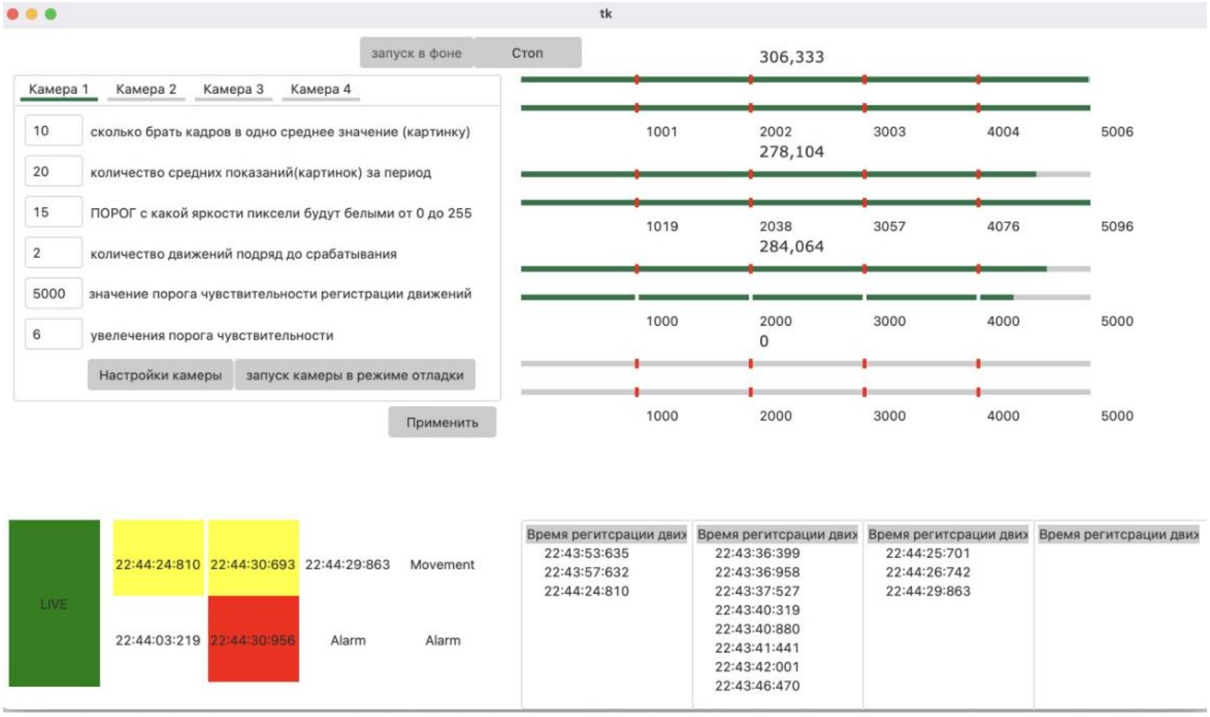


Figure 11. Program window

Under mechanical action, the emitted light changes the light transmission when passing through an optical fiber. In the case of micro-bending, photoelasticity's effect occurs, leading to a change in the refractive index between the shell and the core. In the case of micro-bending, additional losses arising in the optical fiber during mechanical action on it increase, as well as changes in the intensity of the light wave and the phase of its propagation occur. Can convert phase change to amplitude change. Consequently, during mechanical action on the optical fiber, changes like light waves passing through the core of the optical fiber and falling on the surface of the photodetector, in which all changes are recorded, are observed. A photodetector's role in an optical fiber's output is performed by a CMOS photovoltaic array (CMOS) with a measuring channel GPU for preprocessing high-resolution signals. At the end of the optical fiber, a SC type of fiber optic connector with a 2.5 mm diameter tip is installed, and a physical UPC Ultra pin connector is also installed. This makes it possible to form clearer spots of light in contrast to the situation when cutting optical fibers with a knife [15,16]. During the setup process, the focal length between the end of the connector and the surface of the photo matrix is determined. This setting allows the control hardware and software complex to record all changes in the light spot when exposed to the optical fiber.

The program interface is the main window (Figure 12), which provides 1) a launch unit in the background, 2) a camera setup unit, 3) an activity monitoring unit, 4) a button to save the settings "Apply", 5) a block of status indicators and signals, a block of motion registration with time logging.

The hardware and software control system (HSCS) were developed using elements of the OpenCV library (Open-Source Computer Vision Library) [25, 26]. OpenCV is an open-source computer vision library. This library of algorithms is the theory and technology of creating machines that can detect, track and classify objects. OpenCV is implemented based on compiled statistically typed programming languages, and this complex uses a version of Python [26,27]. Graphs are generated and displayed in the Matplotlib library in the Python programming language for data visualization using two-dimensional (2D) graphics (3D graphics are also supported). The generated image can be used as an illustration in the publication. The interface was implemented using the Tkinter library. Tkinter is a cross-platform event-oriented graphics library based on Tk tools [25,26], included in the Python standard library [27,28]. The "Run in the background" button in the block starts the program in normal mode. When the program begins, a reference image is taken to compare all the following with it to measure changes. In the block, the "Stop" button means stopping the program.

There are four tabs in the camera settings block, to configure each channel separately, each tab has six parameter input fields and two function buttons, as well as a button to save the settings of the

"Apply" button. The "Apply" button changes the values of variables and saves them to the "config.ini" file, which should always be located in the same folder as the program, when it starts, all values are loaded from this file. The "Apply" button can be used when the program is running, without stopping, to change parameters and sensitivity in real time. In the camera settings block, the parameter fields are indicated (Figure 13).

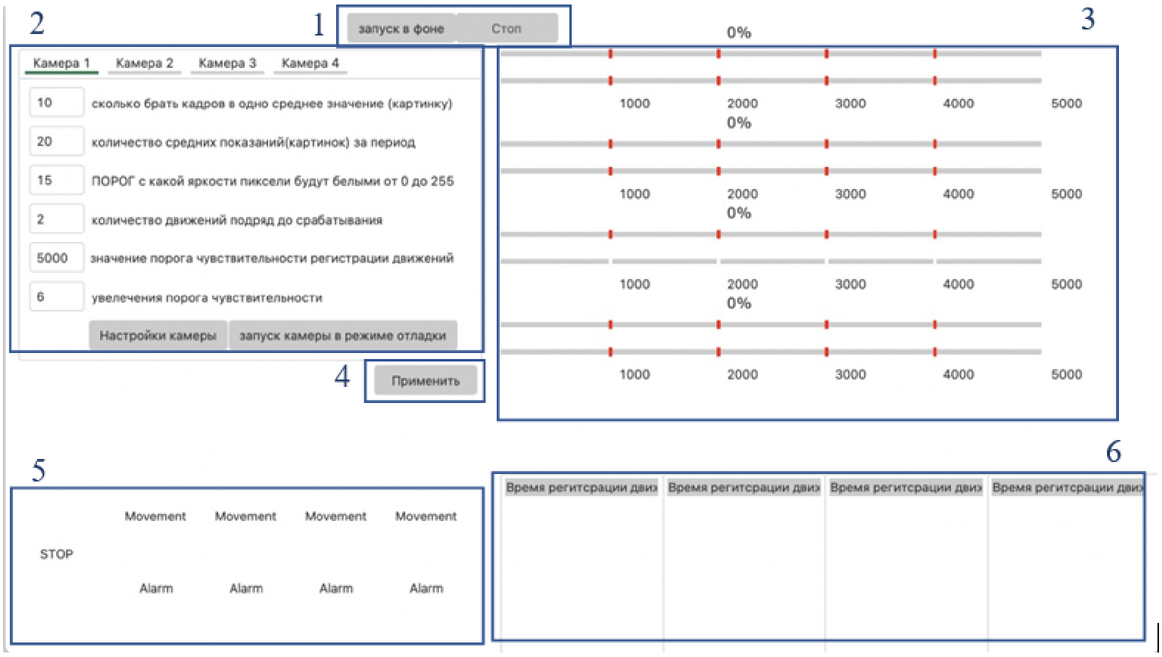


Figure 12. The main window of the HSCS interface

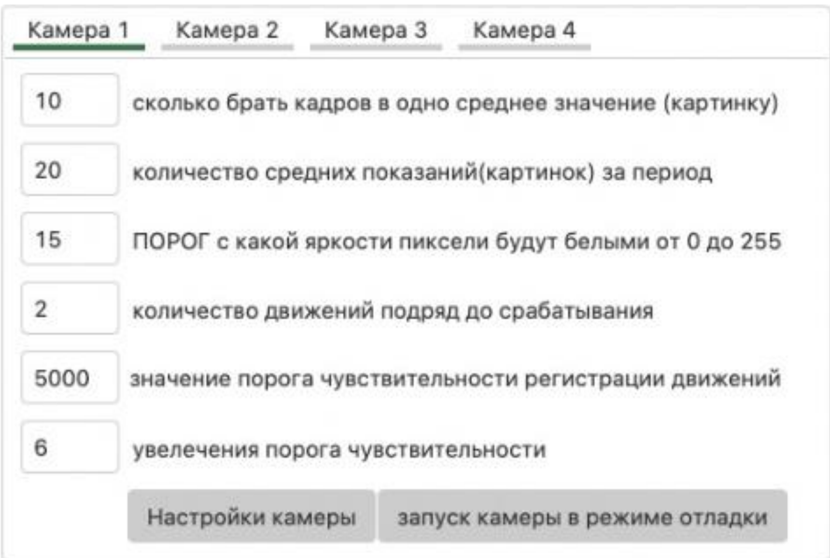


Figure 13. Camera setup block

The number of camera frames that will be averaged into one image is used to reduce camera noise. Increasing the value also increases the detection reaction time. On average, the camera shoots 30 frames per second. For example, if this parameter is set to 10, it will take 10/30 = 1/3 = 0.33 seconds for each image acquisition. After changing this parameter while the program is running, program need to be restarted (press stop and run again) It directly affects the detection sensitivity and reaction time. The number of images (measurements of values) for one detection period. It is used to plot the rate of change and values of values (white pixels) and specify the period – once in how many images (measurements of values) to detect movement Minimum value = 2. The threshold value of the pixel color in grayscale (from 0 to 255), at which it will trigger (turning it white) for counting. 0 = black 255 = white 1-254 =

shades of gray. It directly affects the detection sensitivity. The number of triggers (motion detection) in a row before the ALARM signal. The value of the threshold for triggering motion detection (the number of white pixels), when exceeded, movement will be registered. The value of increasing the sensitivity threshold by a value of N, when registering consecutive movements. If there is no movement, the value will be reset to the original value from field 6.

In the camera settings block, there are function buttons in each "Camera" tab:

1) "Camera Settings".

2) "Running in debug mode"

When you click the "Camera Settings" button, a browser opens with the IP address of the current channel to configure the IP camera in the web interface, to adjust the hardware characteristics of the matrix (Figure 14).

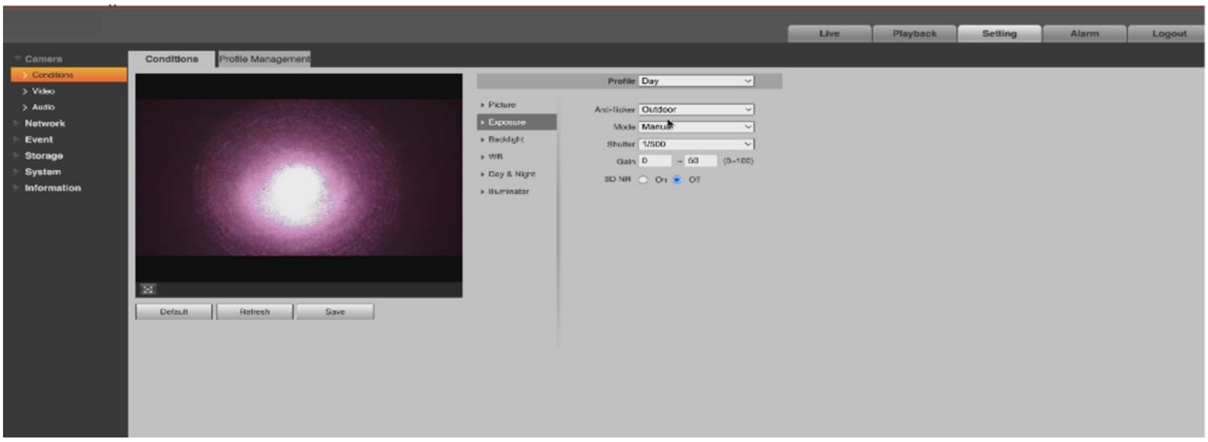


Figure 14. Web interface for camera settings

After pressing the "Start in debug mode" button the setup mode starts. The window of the debugging mode at rest (Figure 15) is a standard window.

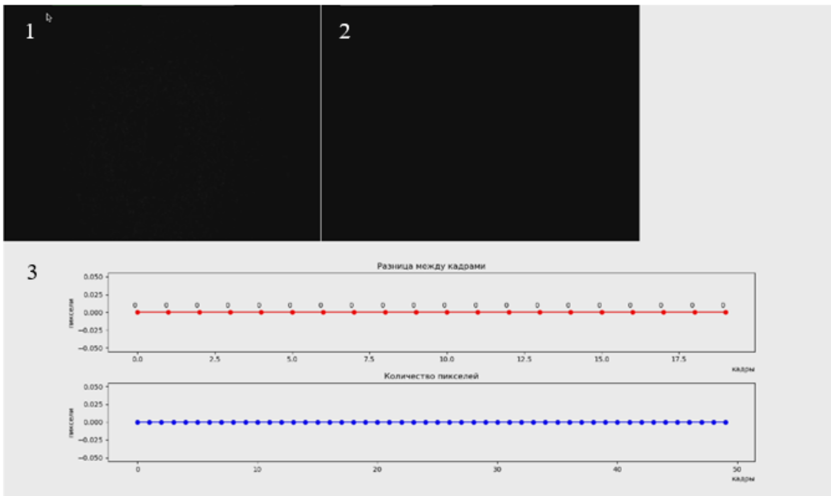


Figure 15. The window of the debugging mode at rest

Running in debug starts the program in the mode of displaying incoming and processed data (Figure 16), consisting of three windows:

- the first window shows the difference between the reference and the current image;
- the second window shows how many pixels (gray dots) worked – exceeded the threshold value and turned into white pixels;
- the third window shows graphs. The upper graph shows the difference (the instantaneous rate of change in the number of white pixels) between two consecutive values of the number of white pixels over time, the lower graph shows the total number of white pixels in each consecutive image.

To stop the program in debug mode, it is enough to close the debug mode window. The activity monitoring block shows marked scales, respectively, for each camera. The scales are:

- the upper one is the number of white pixels whose brightness is higher than the specified brightness threshold;
- the lower one is the changes in the number of pixels above the specified brightness threshold between two consecutive measurements, the scale has a limit set by the field "value of the sensitivity threshold for motion detection". The scale is marked at intervals of 20% of the maximum, indicating numerical values.

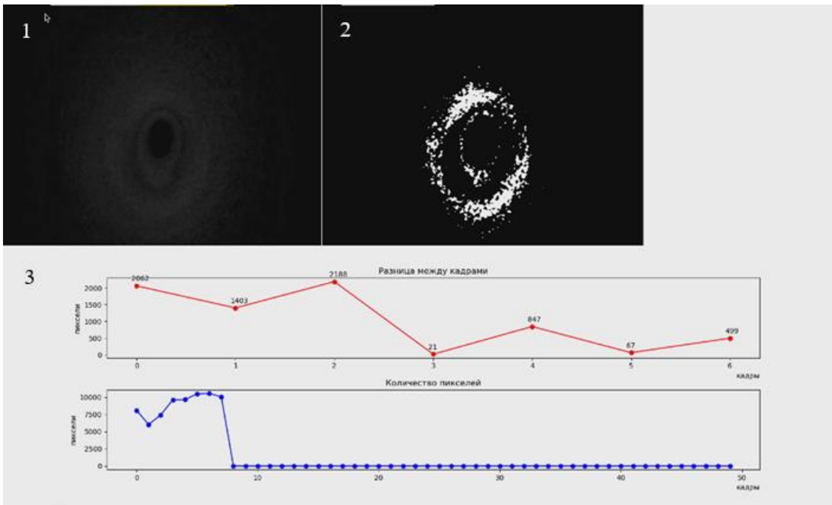


Figure 16. The display mode of incoming and processed data

The block of status indicators and signals is shown in Figure 17.

Figure 17. Block of status indicators and signals in the off position

The program status indicator turns green at start and the label changes to LIVE, when moving or alarm turns white without changing the label LIVE (Figure 18).

Figure 18. Operating mode in the switched-on position

The motion detection indicator turns yellow when triggered and the inscription changes to the exact time of the registered movement, in the absence of movement it turns white (Figure 19). The alarm detection indicator, when a set number of signals are triggered, "movement" turns red, and the inscription changes to the exact time of the registered alarm. Without notice, it turns white (Figure 20). The motion registration unit with time logging, all movements for the current launch are recorded in it, scrolling is carried out with the mouse wheel (Figure 21) . All blocks provide complete information about absolute and speed changes of the spot in real-time with the preservation of the signal response time, and the possibility of total adjustment with the instantaneous application of parameters.

Figure 19. The operation mode of the "motion" signal

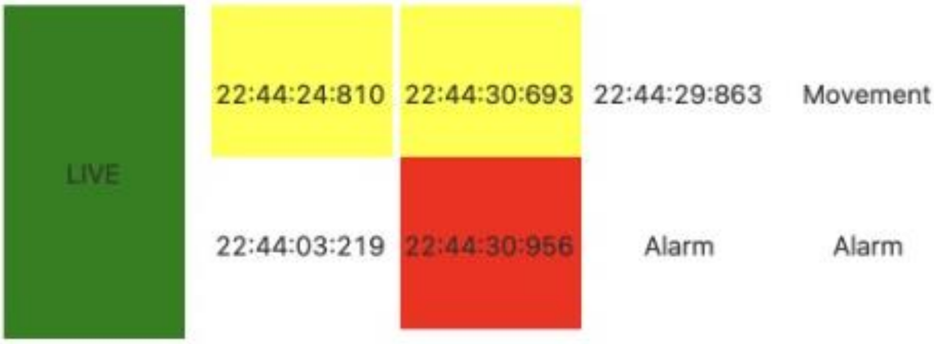
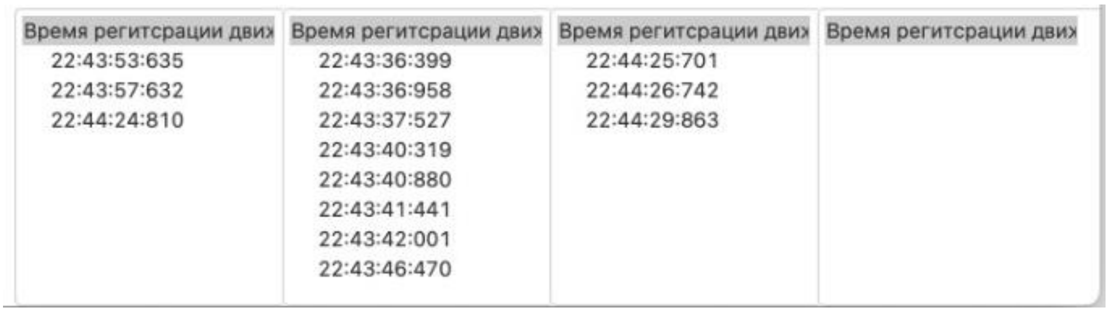


Figure 20. Alarm mode



Время регитсрации движ	Время регитсрации движ	Время регитсрации движ	Время регитсрации движ
22:43:53:635	22:43:36:399	22:44:25:701	
22:43:57:632	22:43:36:958	22:44:26:742	
22:44:24:810	22:43:37:527	22:44:29:863	
	22:43:40:319		
	22:43:40:880		
	22:43:41:441		
	22:43:42:001		
	22:43:46:470		

Figure 21. Traffic registration unit with time logging

4. Discussion

During usual operation, interference may occur due to a violation of laser coherence; stabilization of voltage and current parameters are necessary to reduce them. Permissible deviations at a wavelength of 650 nm should be no more than 5 nm. During laboratory experiments, the fiber-optic was heated to a temperature from 23 to 50 0C, while no false triggering was recorded, respectively. The proposed method for controlling the intensity of the light spot and additional losses is more effective and less dependent on temperature fluctuations, which causes a change in the refractive index of the s. The analysis of the image in Figure 7 shows that there is a fairly high probability of detecting an intrusion into the protected perimeter when exposed to the S, since the system can recognize the intrusion and interference. The pattern of pixels changing from black to white in the event of interference differs from the pattern of pixels during intrusion and exposure to VOS. In the absence of exposure to FOS, their randomly occurring white pixel level is relatively low and can reach 1000 units when exposed to tens of thousands.

The proposed method allows you to control the mechanical effect on the fiber-optic conductor by changing the level of additional losses and changing the intensity of the light wave incident on the surface of the photodetector. Intelligent processing of the spot image allows you to track changes in the intensity of individual pixels. It should be noted that the incident light on the surface of the television matrix contains a significant amount of noise, as seen in Figures 1 and 2. To reduce interference, it is necessary to reduce the noise and pulsation of the radiation source. Noise negatively affects the operation of the system. Still, the intelligent program monitors the dynamics of changes in the shape of the light spot. It can separate fluctuations caused by external factors, for example, external interference, from useful signals when exposed to an intruder. An essential point in the fight against false c is the noise ability of the system to change its sensitivity stepwise; initially, it is set to maximum sensitivity to control the initial offsets and give warning signals to the operator, after which the parameters are automatically roughened for the accuracy of fixing the compensation and eliminating false measurement.

Tests of the system have shown a sufficiently high reliability of operation when exposed to a fiber-optic conductor. The value of the probability of triggering was 0.87. Compared with foreign analogs, the probability of triggering is 0.9-0.95 in various situations, for example, a single violator, a group of violators, or vehicles. In the future, the probability of triggering will be increased to 0.9, while the probability of false triggering will be reduced to 0.1.

5. Conclusions

The purpose of the scientific work has been fully realized, and the result is a developed prototype of an automatic perimeter security system using fiber-optic conductors. A new method is proposed that allows overcoming some disadvantages of the well-known methods of optical interferometry and reflectometry, as well as Bragg fiber gratings, which require rather expensive structural components of ACCSs and specific software based on artificial intelligence. The prospect of creating affordable ACCSs of domestic production, as well as fiber-optic sensors for various industries, is being formed. The proposed ACCS can become an alternative to replace outdated security systems of military facilities using electrical signals, in some cases produced by the former USSR, while blocking and suppression by special means will be completely excluded.

There is a prospect of using the proposed ACCS to protect not only cable channels, but also the perimeters of enterprises, since the distance of the length of the channels in 20 km is quite acceptable for installation in a small enterprise and if several blocks of 64 channels, then this will allow you to control the fence and the ground around the perimeter, while fiber-optic conductors will be laid in several passages, which will not only detect the place of the invasion with an accuracy of 20 to 500 meters, but also indicate the direction of movement of the intruder. The proposed fiber-optic conductors can be integrated into a video surveillance system and have additional controls, for example, unmanned aerial vehicles that will rise into the air at an alarm signal.

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