I.J. Image, Graphics and Signal Processing, **2022, 6, 26-46**
Published Online on December 8, 2022 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijigsp.2022.06.03

Shadow Image Processing of X-Ray Screening System for Aviation Security

Maksym Zaliskyi*
National Aviation University/Department of Telecommunication and Radioelectronic Systems, Kyiv, 03058, Ukraine
E-mail: maximus2812@ukr.net
ORCID iD: https://orcid.org/0000-0002-1535-4384
*Corresponding Author

Olga Shcherbyna
National Aviation University/Department of Electronics, Robotics, Monitoring and IoT Technologies, Kyiv, 03058, Ukraine
Email: shcherbyna_ol@nau.edu.ua
ORCID iD: https://orcid.org/0000-0002-6058-2749

Lidiia Tereshchenko
National Aviation University/Department of Software Engineering, Kyiv, 03058, Ukraine
Email: 10118@ukr.net
ORCID iD: https://orcid.org/0000-0001-8183-9016

Alina Osipchuk
National Aviation University/Department of Telecommunication and Radioelectronic Systems, Kyiv, 03058, Ukraine
E-mail: alina.osipchuk2012@gmail.com
ORCID iD: https://orcid.org/0000-0002-9053-2072

Olena Zharova
National Aviation University/Department of Telecommunication and Radioelectronic Systems, Kyiv, 03058, Ukraine
E-mail: olena.zharova@npp.nau.edu.ua
ORCID iD: https://orcid.org/0000-0002-4060-850X

Received: 07 June, 2022; Revised: 16 July, 2022; Accepted: 24 August, 2022; Published: 08 December, 2022

Abstract: The aviation security is an important component of aviation safety providing. One of the main goals of aviation security service is to detect dangerous and prohibited objects during passengers and baggage screening. For this purpose, aviation security personnel use various equipment: X-ray screening system, body-scans, metal detectors, moving ions detectors, explosive trace detectors. The X-ray screening system gives information on internal structure of baggage. The main disadvantage of X-ray screening system is rather high level of the false alarm probability. This requires developing new methods of image processing and recognition of dangerous and prohibited objects on the background of other objects. This article develops the principles of shadow image processing while screening the baggage using X-ray system to fix the mentioned disadvantage. The math equation for shadow image is obtained based on the laws of geometry and Beer-Lambert equation taking into account the chosen scanning technique. Based on this, the article is focused to the analysis of simple objects images and their application for complex objects recognition. The article discusses the example of handgun recognition using a new approach based on spectral analysis of developed shadow images. The results of the research can be used for improvement of algorithmic toolkit in aviation security automatic decision-making system while screening the baggage by X-ray equipment.

Index Terms: Aviation Security, X-Ray Equipment, Shadow Image Reconstruction, Objects Recognition, Scanning Methods.

1. Introduction

Safety is the key point for general, corporate, military and commercial aviation [1]. The safety is the condition, for which risks of aviation events are reduced and controlled to an acceptable level [2]. Maintaining and increasing the level of safety is the most important task for civil aviation [3, 4].

Aviation safety can be considered as a dynamic stochastic process [5, 6] that depends on many factors including airport organizational structure, reliability of aviation equipment, human factor, environmental conditions [2, 7]. The aviation safety depends on the influence of unintentional and deliberate actions. The unintentional actions are associated with the random occurrence of different aviation events. For example, the aircraft safety depends on: a) the serviceable operation of radio equipment of flight providing such as radar, navigation systems, communication devices [8]; b) the efficiency of data processing techniques for modern radio equipment in different environmental conditions [9, 10]; c) the psychological state of the pilot, especially in a stressful situation [6].

The deliberate actions are associated with aviation security. The aviation security is an important component for safety of aviation providing. The purpose of aviation security services is to ensure aviation safety, the efficiency of civil aviation airports by implementing measures to protect against acts of unlawful interference in accordance with current rules, recommended practices and procedures [11].

In order to evaluate the planning of civil aviation security measures, a general strategy should be developed taking into account the trends in the occurrence of threats and international requirements [12]. The main principles that regulate the aviation security service are following:

– security measures applied at a specific airport or aerodrome must be adequate to the level of threat to civil aviation that exists at a specific time;

– any civil aircraft may not fly outside the certain country without the permission of the civil aviation authority;

– any person may not be admitted on board of aircraft located in a restricted area of airport without a valid reason;

– any person or vehicle may not enter or pass through the restricted area of the airport without passing established security control procedures;

– items, as well as hand luggage, baggage, courier and express items, mail, on-board supplies excluding standard equipment of the aircraft, may not be placed on board without passing security control;

– all aviation personnel and other specialists (persons), whose work belongs to the branch of interests of civil aviation and concerns the interests of aviation security, may be allowed to perform such work only after they graduate appropriate training.

Based on a systematic approach and analysis, the International Civil Aviation Organization (ICAO) identified the main threats to aviation safety: hijacking of aircraft by terrorists and other criminal elements and acts of sabotage; illegal transportation of dangerous goods; dangers during aircraft flights caused by aggressive or mentally unbalanced passengers; use of surface-to-air missiles by terrorists; illegal transportation of nuclear and radioactive substances; cyberterrorism.

While planning aviation security, it is necessary to solve the following problems:

1. Minimization of explosions impact. In paper [13], the analysis of using conventional explosives in attacks on airports is carried out and recommendations are given for the detection and disposal of improvised explosive devices placed in vehicles or baggage items.

2. The protection of passengers and personnel. This is a primary problem, which means the practical development of permanent or temporary protection of air transport passengers, service personnel and visitors from attacks with the use of firearms and grenades [14]. Solution of this problem is associated with recommendations for the use of bulletproof fabrics, materials capable of resisting explosions or grenades, as well as for preventing (in the interests of the customs service) the transfer of contraband goods from one group of violators to another.

3. Access control. Reducing the number of full-time employees who need access to restricted areas is an obvious, but often ignored security measure [15]. Baggage drop-off points are often located in restricted area where they should not be. In places where baggage is issued to passengers of international lines, the requirements of the local customs service can be ensured by other means, but taking out the baggage places from the restricted zone can significantly reduce the risk of passengers re-entering this zone and provide the impossibility to enter it by unauthorized persons.

4. Perimeter protection. This problem is often treated as secondary, although the lack of such protection creates favorable conditions for terrorists to attack airport infrastructure or aircraft and is often the object of criticism from the mass media, usually in connection with some aviation incidents. Solution of this problem is associated with usage of technical devices of alarm system, security closed television systems, lighting and passive infrared detectors [16].

5. Protection against cyberterrorism. Threats of cyberterrorism are new and, at the same time, the most dangerous threats of the 21st century [17]. Cyberterrorism can manifest itself in various forms. The simplest of them is psychological warfare aimed at spreading disinformation using mass media to disrupt the normal operation of airports and airlines [18]. This can cause the refusal of air passengers to fly, which will affect the economy of countries that depend on civil aviation. Other dangerous threats of cyberterrorism can lead to serious disturbances with fatal consequences for people, disorganization of airports and damage to aircraft in flight. The actions of cyberterrorists against airports and airplanes are significantly different from traditional terrorist and criminal attacks on civil aviation facilities. Cyberterrorists can, acting from one location, affect events in hundreds of other locations on a global scale.

Solution of this problem is associated with development of new methods for detecting DDoS attacks [19], cyber incidents [20], analysis of the security of sites and equipment with access to the Internet [21], analysis of the efficiency of the use of information web-resources [22] and others.

One of the main goals of aviation security service is to detect dangerous and prohibited objects during passengers and baggage screening [23]. For this purpose, aviation security personnel use various equipment: X-ray screening system, body-scans, metal detectors, moving ions detectors, explosive trace detectors. Modern airports use three to five levels of inspection for baggage. The screening of passengers is carried out line mode. The X-ray screening system provides information on internal structure of baggage objects and gives possibility to detect explosives, narcotics, firearms, cold weapon and other dangerous and prohibited objects [24].

2. Analysis of Signal Processing at X-ray Screenning and the Research Problem Statement

According to the modern recommendations of air terminals building, it is assumed that all baggage undergoes automatic inspection with the help of X-ray screening systems. Unfortunately, the high reliability of detection of dangerous objects and materials (the probability of correct detection is above 0.99) is also accompanied by high levels of the false alarm probability (this probability is approximately equal to 0.15 ... 0.3) [24, 25]. The timely and correct detection of dangerous and prohibited objects has significant influence not only the aviation safety, but also aircraft departures and arrivals delays [26], increasing the throughput rates for each aviation security inspection line [27].

The main reasons of rather high level of the false alarm probability are:

1. Dependence of detection performance on obtained image quality [28].
2. Disadvantages in terms of probabilistic characteristics of imaging technologies and used algorithms for recognition of dangerous and prohibited objects while X-ray screening [29].
3. Human factor [30].
4. Equipment malfunction and failures [31, 32].

The human factor is taken into account mainly through the aviation personnel training. At the same time, special software is being developed, such as threat image projection. This software is installed on X-ray screening systems [33]. Threat image projection generates and puts fictitious images of dangerous objects on X-ray images of real baggage that is being checked. In addition, paper [34] analyses the color compositions obtained based on threat image projection merging algorithm. The authors proved that this algorithm increases the efficiency of detection and confidence level, provides shorter reaction times compared with standard technique of computer-based X-ray screening training images.

The methods of operational efficiency increasing suppose improvement of maintenance techniques [35, 36] and equipment diagnostics and repair [37], reliability analysis for deteriorating systems [38, 39], developing methods of statistical data processing [40, 41], implementation of control and support system for equipment lifecycle.

Literature analysis showed that sufficient attention is paid to X-ray image processing. The overview of digital image processing technology is presented in [42]. Traditional techniques for X-ray image processing are considered in [43]. The processing algorithms can be conditionally divided to detection algorithms [44], objects parameters estimation algorithms [45], contour selection algorithms [46].

The use of automated technologies for detection and recognition of dangerous and prohibited objects in the screening process allows aviation security operators to focus on aspects of the screening, while the system performs the functions of scanning, analyzing and detecting objects in baggage [47]. Paper [48] presents method for automated detection of threat objects using adapted implicit shape model. This approach uses a visual vocabulary for the dangerous and prohibited objects to be detected. The authors [48] demonstrate sufficiently low level of probability of false alarms in case razor blades and shuriken detection (0.02 and 0.06, respectively), but in case of handguns detection the level of false alarms is high (the probability is equal to 0.18) at the similar level of detection probability.

The modern tool of recognition of dangerous and prohibited objects is the use of deep Convolutional Neural Networks (CNN). Paper [49] concentrates on the pre-trained CNN based on transfer learning paradigm. The proposed approach showed efficient handguns detection with low false alarms probability (in the range 0.0021 … 0.024 depending on parameters of CNN). The analysis of probability characteristics for various object detection using CNN is presented in [50]. There are some improvements and modifications of CNN like demonstrated in [51]. In general, CNN is effective and robust technique of dangerous and prohibited objects detection [52], but it requires significant computing power.

The literature considers various methods of processing and recognition in different fields, in particular, those given in publications [53–60], which could be adapted for automated screening systems. Some new ideas of signal processing developed for adjacent applications [54, 55, 61, 62] can also be considered as potentially useful approaches. However, the task of signal and image processing to improve X-ray screening efficiency for aviation security application is a very complicated and specific task with special requirements, in particular, limited processing time. Different things consisting the content of a baggage unit, when being radiated, can form some shadows on a conditional screen. These shadows for sure contain important information. The question is: how to retrieve useful data by processing these shadow images?

Thus, the article concentrates on this new approach for image processing. So, the aim of this article is to analyze the principles of shadow image reconstruction and processing while screening the baggage using X-ray system.

Proceeding to the task formulation, it is reasonable to note that an X-ray system is based on the direct imaging method that contains the following operations:

– irradiation of object with X-ray source in configuration space,
– scattered or attenuated radiation receiving,
– conversion of received radiation into an electrical signal and signal processing,
– electrical-to-optical signal conversion [24, 63].

The second operation is associated exactly with the shadow images reconstruction. The shadow image of the inspected object is the shadow of the object in the X-ray range. Because the different objects absorb X-ray radiation, then shadow image shows the amplitude distribution for X-ray radiation on the receiving screen after its propagation through the inspected object.

The idea of shadow image reconstruction was mentioned in some researches, for example, for medical applications. In particular, publication [64] considers analytical reconstruction technique for images called model-based iterative reconstruction. The authors present two examples of shadow reconstruction. The first example focuses on passing several X-ray pencil beams through a collimator, an image voxel, and a detector cell. These pencil beams have different X-ray photon paths through the object and are eventually approximated by a weighted sum of many simplified integral models. However, this process takes a long time. The second example in [64] is reconstruction of the shadow cast by each image voxel on the detector and use point response functions. In this example, only one ray is discarded between the source and the center of the image voxel to determine the intersection point at the detector, and the response function is used to distribute the contribution of the image voxel to different detector cells during the direct projection. The intensity of the received radiation at the detector is non-stationary and varies depending on the location of the voxel to account for different magnifications and orientations. The authors of this publication argued that second approach is more computationally preferable.

Paper [65] deals with the method of shadow formation process during image analysis. In this research, the procedure for determining the shape of the shadow of voxel model using its discrete matrix representation is considered. Proposed by authors algorithm determines all the edges of the general parallelepiped-voxel model that influence on the formation of the shadow. For these edges, the direction in which the shadow propagates is determined. For each component of the discrete-matrix model, the presence of an obstacle for the formation of a shadow in a given direction is established and corresponding shadow is obtained at the screen.

Paper [66] investigates the method of distance-driven projection and backprojection in three dimensions for X-ray systems. Authors analyzed different projection and backprojection methods in terms of signals re-sampling. In case of one dimensional signals, authors [66] used the linear interpolation kernel operation. This research also extends the distance-driven framework to three dimensions and substantiates its usage in case of cone beam image reconstruction.

There are other approaches for shadow images obtaining. The research [67] concentrates on analysis statistical image reconstruction methods for transmission tomography, including X-ray systems. Paper [68] considers data processing and image reconstruction methods for pixel detectors. In paper [69], the reference sphere method is analyzed for shadow image reconstruction.

Thus, the literature overview shows that the reconstruction of shadow images is a promising direction, which in particular is aimed at improving the efficiency of the operation of X-ray screening systems.

Based on the above analysis, the mathematical description for attenuated radiation by objects inspected using X-ray screening system can be given in general form as follows:

$$\varphi(x, y) = \Psi(\vec{F}, \vec{G}, \vec{P}, \vec{I}), \qquad (1)$$

where x and y are abscissa and ordinate coordinates at the receiving screen; $\vec{F}$ is a form parameter that sets the complexity of inspected object (it can be simple or complex); $\vec{G}$ is geometric parameters of inspected object, which specifies numerical value of its dimensions; $\vec{P}$ is physical parameters of inspected object (density, attenuation, absorption coefficient, scattering coefficient and others); $\vec{I}$ is parameters of inspected object inclination with respect to coordinate axes.

Mathematically this article aims describing the approach for determining attenuated radiation $\varphi(x, y)$ at the screen and analyzing the possibility this dependence usage for dangerous and prohibited objects recognition.

Mentioned above analysis gives the possibility to formulate the summary statement about research objectives of this article:

1) to develop the simple method of shadow image processing while screening the baggage using X-ray system based on the laws of geometry and Beer-Lambert equation;

2) to obtain the mathematical description of simple objects images using proposed method;

3) to analyze the application of simple objects images for complex objects shadows reconstruction;

4) to develop new approach of dangerous and prohibited objects recognition based on two-dimensional spatial spectrum of shadow images;

5) to examine handgun recognizer according to proposed approach using statistical simulation.

Research objectives are directed to reduce the false alarm probability of X-ray screening system with requirements of high level of correct detection and low computing time.

3. Method of Shadow Images Reconstruction

The generalized structure of screening systems includes radiation sources, inspected object and receiving part. The receiving part includes equipment for images processing and displaying information for screeners. In the processing unit, information about the shadow image of inspected object is formed.

The inspected object is placed between the radiation source and the screen at a certain distance [63]. At each point of the screen, the value of the radiation parameter that passed through the object (amplitude, polarization and others) is recorded. Each value of this parameter corresponds to a certain brightness of the optical image. In the general case, the optical image brightness distribution is also a three-dimensional function and depends on imaginary coordinates (x, y, z). In the following analytical models, the distribution of the brightness of the optical image is set similarly to the spatial distribution of the real parameter. Since the spatial parameter is a constant value within a certain volume, the brightness function of the optical image within this certain volume is also constant value. This volume is bounded by the two-dimensional function $\varphi'(x, y)$. The resulting optical image is displayed on the monitor of X-ray screening system and is therefore two-dimensional. Coordinates (x, y) set a certain point on the monitor screen. So, in fact, the brightness of the image is determined by a two-dimensional function $\varphi'(x, y)$.

In general, in order to improve the operational efficiency of screening system, it is necessary to continuously improve the structure of data processing, because: a) the diversity of inspected objects is constantly increasing, b) objectively there are noises of various origins, c) the volume of air transport is increasing, d) the time of decision-making regarding the detection of prohibited objects is decreasing [24]. In these conditions, the issue of using new theoretical results in the field of data processing, in particular, statistical and filtering methods of signal processing, becomes relevant. At the stage of synthesis and analysis of data processing structures, it is advisable to use methods and means of electronic modeling and statistical simulation [43].

Fig. 1 shows the generalized structure of data processing operators for X-ray screening systems.

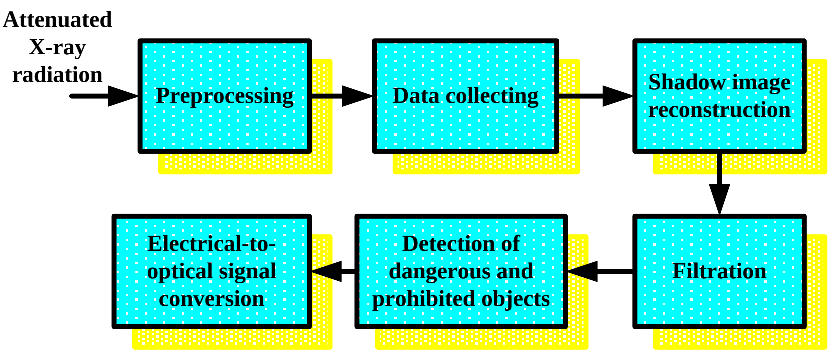

Fig. 1. The generalized structure of data processing operators for X-ray screening systems.

A generalized methodical approach to the construction of shadow images of objects of various shapes includes the following steps:

1. Selection of the type of radiation source and analysis of its physical features, as well as the scanning method. For example, if the source is point, then the wave has a spherical front, if the source is linear, then it has cylindrical front.
2. Analysis of the geometric features of the inspected object and its location relative to the radiation source, formation of input data vectors (dimensions, distance from the source to the OC inspected object distance from the inspected object to the screen and others).
3. Analysis of the electromagnetic radiation propagation through the inspected object to the receivers (screen, detectors). These phenomena obey Beer-Lambert equation and the laws of geometry.
4. Formation of shadow image and its coding in a pseudo-color scale.

According to Beer-Lambert equation, the intensity $|E|^2$ of radiation that propagates in a homogeneous environment (α = const) is described by the following expression:

$$|E|^2 = E_0^2 \exp(-\alpha\Delta), \tag{2}$$

where α is an absorption coefficient for the inspected object material; Δ is a distance over which X-ray propagated inside the inspected object, E_0^2 is an intensity of radiation before hitting the inspected object.

The basic laws of geometry for constructing shadow images include:

– rules of triangles similarity,
– the Pythagorean theorem,
– theorems of sines and cosines,
– formulas for determining the trigonometric functions of the angles of a right triangle.

Consider the features of determining the shadow images of the simplest objects. Let the object is a parallelepiped. The location of parallelepiped in the screening system is shown in Fig. 2.

Assume that the radiation source is point. The parallelepiped has dimensions (*a*, *b*, *c*). The distance between the radiation source and the inspected object is equal to *d*. The distance between the inspected object and the screen is equal to *e*. The inspected object has homogeneous structure, so α = const. The line connected the center of mass of parallelepiped and radiation source is perpendicular to the screen.

To obtain general mathematical equation for shadow image, first consider shadow image formation in one plane and after that use the method of scanning.

The projection of parallelepiped location in the plane perpendicular to ordinate axis is shown in Fig. 3.

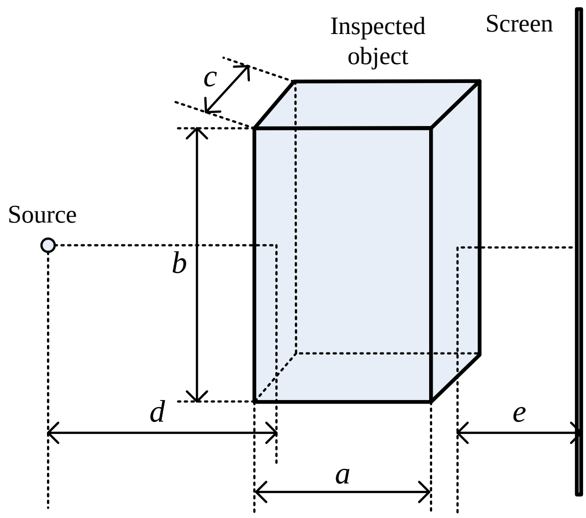

Fig. 2. The location of parallelepiped in the screening system.

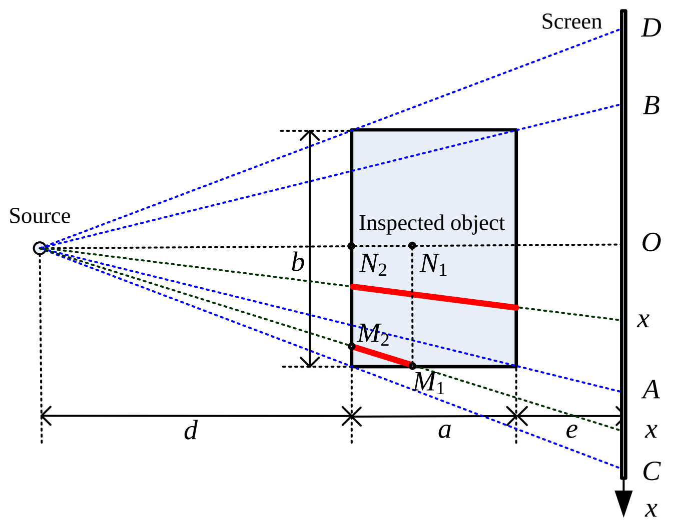

Fig. 3. The projection of parallelepiped location in the plane perpendicular to ordinate axis.

The abscissa axis corresponds to the down direction on the screen surface. The origin of the coordinate system is located on the screen surface at the point *O*, to which the perpendicular from the source is directed. The shadow equation will be an even function, so the calculation will be performed only for positive values.

At the first stage of calculations, we will draw rays from the source to the vertices of the rectangle (in Fig. 3 they are indicated by blue dotted lines). It is obvious that *OA* = *OB*, *OC* = *OD*. According to the rule of similarity of right triangles, we can write the proportions

$$\frac{OA}{b/2} = \frac{d+a+e}{d+a} \text{ and } \frac{OC}{b/2} = \frac{d+a+e}{d}.$$

and

$$\frac{OC}{b/2} = \frac{d+a+e}{d}.$$

So

$$OA = \frac{0.5b(d+a+e)}{d+a} \text{ and } OC = \frac{0.5b(d+a+e)}{d}. \tag{3}$$

At the second stage of calculations, we will draw two rays from the source to the screen. One ray hits a point at the segment *OA*, and another ray hits a point at the segment *AC*. It is necessary to determine the distances Δ inside inspected object (in Fig. 3 they are indicated by red segments).

Consider the first ray. To determine considered segment, we find hypotenuse of right triangle with vertices at the source, point *O* and point *x* at the segment *OA*

$$h = \sqrt{x^2 + (d+a+e)^2}.$$

According to the rule of similarity of right triangles, we can write the proportion

$$\frac{\Delta}{h} = \frac{a}{d+a+e}.$$

So

$$\Delta = \frac{a}{d+a+e}\sqrt{x^2 + (d+a+e)^2}. \tag{4}$$

Consider the second ray. The right triangle with vertices at the source, point *O* and point *x* at the segment *AC* has the hypotenuse

$$h = \sqrt{x^2 + (d+a+e)^2}.$$

According to the rule of similarity of right triangles, we can write the proportions

$$\frac{h_1}{h} = \frac{b/2}{x} \text{ and } \frac{h_2}{h} = \frac{d}{d+a+e},$$

where h_1 is a hypotenuse of right triangle with vertices at the source, point M_1 and point N_1, h_2 is a hypotenuse of right triangle with vertices at the source, point M_2 and point N_2.

It is obvious that

$$\Delta = h_1 - h_2 = \left(\frac{b}{2x} - \frac{d}{d+a+e}\right)\sqrt{x^2 + (d+a+e)^2}. \tag{5}$$

Taking into account equations (3), (4) and (5), we can determine the mathematical equation for shadow

$$\Delta(x)=\begin{cases}\dfrac{a}{d+a+e}\sqrt{x^2+(d+a+e)^2}, \text{if } |x|\le\dfrac{0.5b(d+a+e)}{d+a},\\ \left(\dfrac{b}{2|x|}-\dfrac{d}{d+a+e}\right)\sqrt{x^2+(d+a+e)^2}, \text{if } \dfrac{0.5b(d+a+e)}{d+a}\le|x|\le\dfrac{0.5b(d+a+e)}{d},\\ 0, \text{ otherwise.}\end{cases} \tag{6}$$

The examples of obtained shadow are shown in Fig. 4.

The shadows were obtained for the following initial data: $a=5$, $b=6$, $e=3$, $d=7$ for the first shadow and $d=30$ for the second shadow. The first shadow is edge-effected. In this case, edge distortion occurs, which affects the image quality. The second shadow has less edge effect. In general, analysis shows that the level of edge effect depends on ratio d/e. Increasing this ratio leads to a decrease in the influence of the edge effect on image quality.

To obtain the final mathematical model of shadow image at the screen of receiver, consider the method of scanning, the features of which is shown in Fig. 5.

It is better to consider the scanning process in a cylindrical coordinate system. The abscissa axis coincides with ρ-axis. In this case, the scanning plane changes depending on the inclination angle θ. The section of the parallelepiped for different inclination angles θ is rectangle with side $B(\theta)$. The projection of parallelepiped location in the plane for different inclination angles θ will be the similar as in Fig. 3, but instead of b we obtain $B(\theta)$. According to cosine function definition

$$B(\theta)=\frac{b}{\cos\theta}. \tag{7}$$

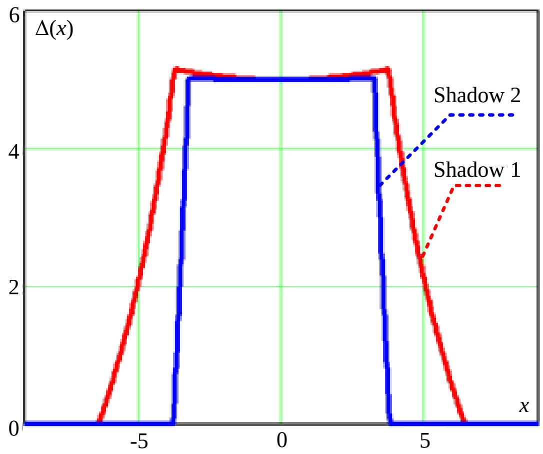

Fig. 4. The examples of obtained shadow.

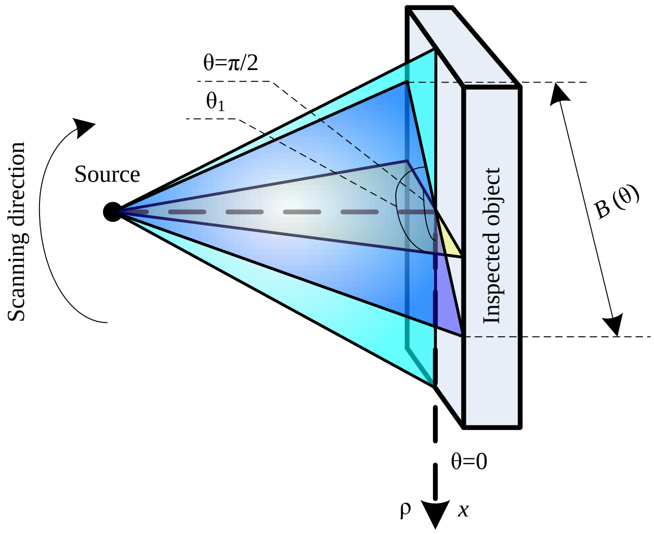

Fig. 5. The examples of obtained shadow.

For the convenience of functions forming, we make inverse transition from the cylindrical coordinate system with the arguments ρ and θ to the Cartesian coordinate system with the arguments x and y. This operation is carried out with the help of known formulas

$$\theta(x,y) = \operatorname{arctg}\frac{y}{x},$$

$$\rho(x,y) = \sqrt{x^2 + y^2}.$$

Using equations (6), (7) and explained method of scanning with transition to cylindrical coordinate system and inverse transition, after mathematical simplification the final equation for shadow image of parallelepiped can be presented as follows

$$\Delta(x,y) = \begin{cases} \frac{a}{d+a+e}\sqrt{x^2+y^2+(d+a+e)^2}, \text{if } |x| \le \frac{0.5b(d+a+e)}{d+a}, |y| \le \frac{0.5c(d+a+e)}{d+a}, \\ \left(\frac{b}{2|x|} - \frac{d}{d+a+e}\right)\sqrt{x^2+y^2+(d+a+e)^2}, \text{if } \frac{0.5b(d+a+e)}{d+a} \le |x| \le \frac{0.5b(d+a+e)}{d}, |y| \le \frac{c}{b}|x|, \\ \left(\frac{c}{2|y|} - \frac{d}{d+a+e}\right)\sqrt{x^2+y^2+(d+a+e)^2}, \text{if } \frac{0.5c(d+a+e)}{d+a} \le |y| \le \frac{0.5c(d+a+e)}{d}, |y| \ge \frac{c}{b}|x|, \\ 0, \text{ otherwise.} \end{cases} \quad (8)$$

Equation (8) presents the shadow image in logarithmic scale. Real value shadow image can be get after Beer-Lambert equation (2) usage, but in case of pseudo-color scale utilization, logarithmic scale gives more opportunity for subsequent recognition of certain objects.

The example of shadow image for parallelepiped is shown in Fig. 6.

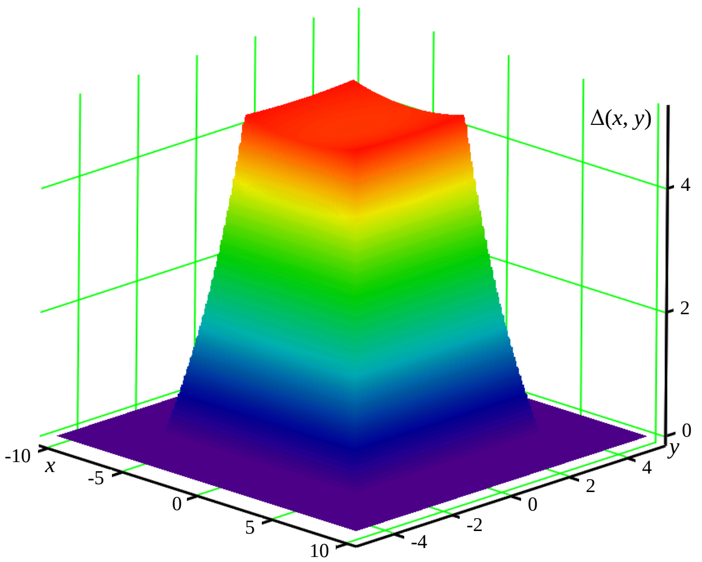

Fig. 6. The example of shadow image for parallelepiped.

The shadow image in Fig. 6 was obtained for the following initial data: $a = 5$, $b = 6$, $c = 3$, $d = 7$, $e = 3$. This image is influenced by edge effect, and has significant distortion. The two-dimensional shadow images on the screening system monitor are shown in Fig. 7.

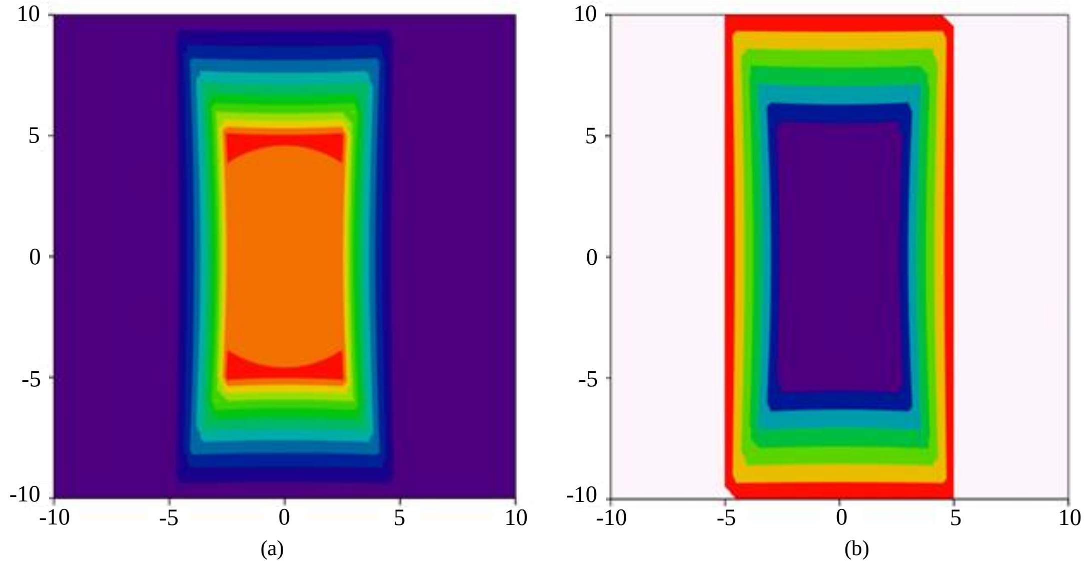

Fig. 7. The two-dimensional shadow images on the screening system monitor: a) in logarithmic scale, b) in usual pseudo-color scale.

Consider determining the shadow image for another simple object. Let the inspected object is a sphere. The projection of sphere location in the plane perpendicular to ordinate axis is shown in Fig. 8.

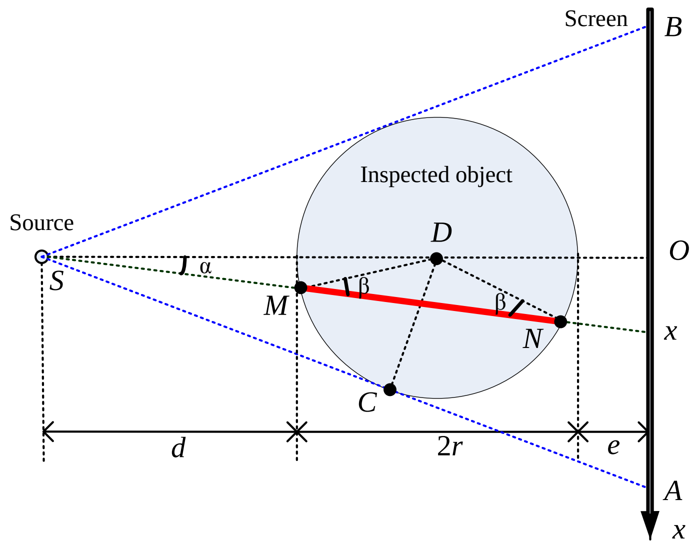

Fig. 8. The projection of sphere location in the plane perpendicular to ordinate axis.

Perform calculations making similar assumption as for parallelepiped. The leg of right triangle *SCD* is

$$SC = \sqrt{(d+r)^2 - r^2} = \sqrt{d^2 + 2dr} \,.$$

According to the rule of similarity of right triangles *SCD* and *SOA*, we can write the proportions

$$\frac{OA}{DC} = \frac{OS}{SC}$$

or

$$\frac{OA}{r} = \frac{d+2r+e}{\sqrt{d^2+2dr}} \,.$$

So

$$OA = \frac{r(d + 2r + e)}{\sqrt{d^2 + 2dr}}. \tag{9}$$

For triangle *MDN*, where *MN* = Δ, according to law of sines

$$\frac{\Delta}{\sin 2\beta} = \frac{r}{\sin\beta}.$$

Then

$$\Delta = \frac{r\sin 2\beta}{\sin\beta} = 2r\cos\beta. \tag{10}$$

For triangle *MDN* according to law of sines

$$\frac{d + r}{\sin\beta} = \frac{r}{\sin\alpha}.$$

or

$$\sin\beta = \frac{d + r}{r}\sin\alpha.$$

Taking into account that

$$\sin\alpha = \frac{x}{\sqrt{x^2 + (d + 2r + e)^2}}.$$

we can get

$$\sin\beta = \frac{d + r}{r}\frac{x}{\sqrt{x^2 + (d + 2r + e)^2}}.$$

Taking into account equations (9), (10) and transition from sine to cosine function, we can determine the mathematical equation for shadow

$$\Delta(x) = \begin{cases} 2\sqrt{r^2 - \frac{x^2(d + r)^2}{x^2 + (d + 2r + e)^2}}, \text{if } |x| \le \frac{r\sqrt{d^2 + 2dr}}{d + 2r + e}, \\ 0, \text{ otherwise.} \end{cases} \tag{11}$$

Using equation (11) and the same method of scanning with transition to cylindrical coordinate system and inverse transition, after mathematical simplification the final equation for shadow image of sphere can be presented as follows

$$\Delta(x, y) = \begin{cases} 2\sqrt{r^2 - \frac{(x^2 + y^2)(d + r)^2}{x^2 + y^2 + (d + 2r + e)^2}}, \text{if } x^2 + y^2 \le \frac{r^2(d + 2r + e)^2}{d^2 + 2dr}, \\ 0, \text{ otherwise.} \end{cases} \tag{12}$$

The example of shadow image for sphere is shown in Fig. 9. The shadow image in Fig. 9 was obtained for the following initial data: $a = 5$, $r = 4$, $d = 7$, $e = 3$. This image is influenced by edge effect, and has significant distortion. The two-dimensional shadow image on the screening system monitor is shown in Fig. 10.

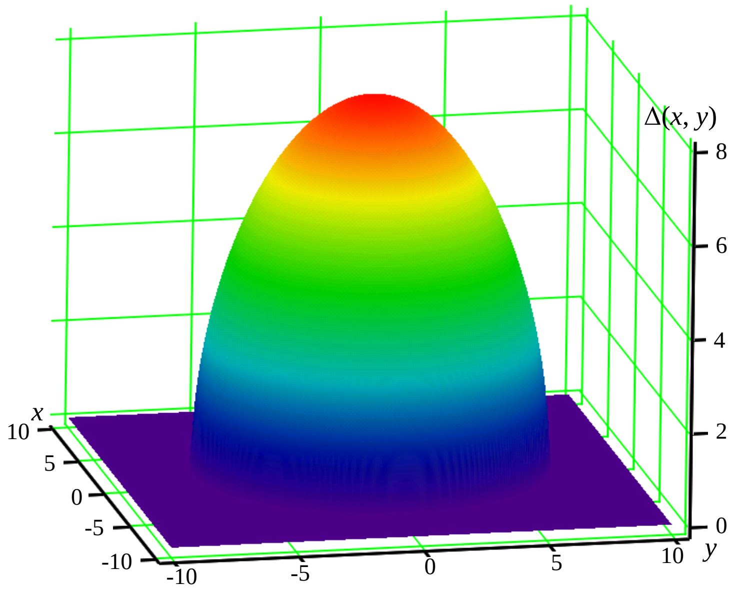

Fig. 9. The example of shadow image for sphere.

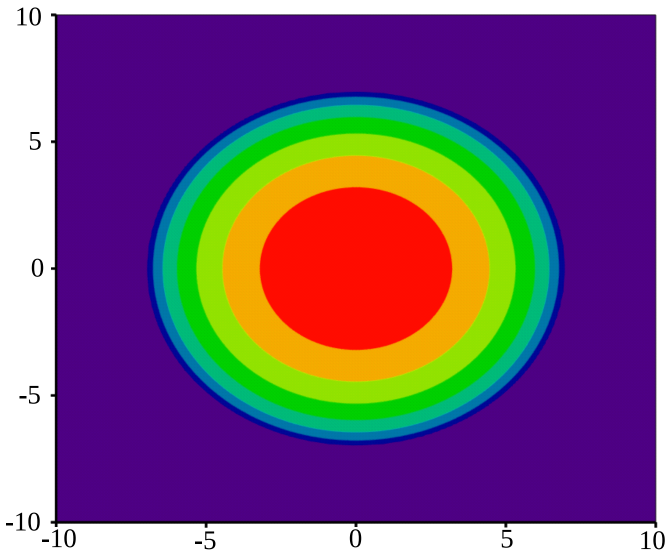

Fig. 10. The two-dimensional shadow image for sphere on the screening system monitor in logarithmic scale.

Similar procedures can be repeated to reconstruct shadow images of other simple-shaped objects. According to the authors opinion, such objects are a cone, a pyramid, a cylinder and a torus.

The basic feature of discussed method of shadow images reconstruction is possibility to obtain the mathematical equations for inspected object description. Such feature allows developing efficient methods of dangerous and prohibited objects recognition in terms of minimizing the false alarm probability for low computing time. In addition, this technical property gives the ability to implement it in real scenario while screening the baggage using X-ray aviation system.

4. Complex Objects Analysis

Consider the principles of formation of shadow images for objects of complex shape. Let vector of form parameter in (1) contains two components $\vec{F} = \{\vec{f}, \vec{g}\}$, where $\vec{f}$ is vector of simple objects, $\vec{g}$ is vector of complex objects. To describe the objects of simple shape, the following definitions are used:

– object f_1 is parallelepiped;
– object f_2 is sphere;
– object f_3 is cone;

– object f_4 is cylinder;

– object f_5 is pyramid;

– object f_6 is torus.

Complex objects are arbitrary objects that can be presented as a sum or intersection of other objects. Simple-shaped objects allow determining wide range of complex-shaped objects by using operations of intersection, association, conglutination and others. With the help of these operations, it is possible to research the shadows of complex objects and compile a database of these objects, which allows improving the detection of dangerous objects and reducing false alarm for aviation security services.

If $\cap$ is intersection operation (object inside another object), $\cup$ is association operation, then example of complex objects will be:

– object $g_1 = f_2 \cap f_2$ is object of complex shape of type “sphere inside sphere”;

– object $g_2 = f_1 \cup f_1$ is object of complex shape of type “parallelepiped near parallelepiped”;

– object $g_3 = f_1 \cup f_3 \cap f_3$ is object of complex shape of type “a parallelepiped next to a cylinder that has another cylinder inside” (the model of handgun);

– object $g_4 = f_1 \cup f_2 \cup f_5$ is model of knife.

In addition, the considered method of forming shadow images can be used to obtain mathematical models for arbitrary location of the source, the inspected object and the screen.

Consider a possible variant of using shadow images for recognizing dangerous and prohibited objects. For these purposes, we analyze the spectra of two-dimensional images.

The two-dimensional spatial spectrum (the Fourier image $\Phi(\omega_x, \omega_y)$) can be found according to two-dimensional Discrete Fourier Transform:

$$\Phi(\omega_x, \omega_y) = \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} \varphi(x, y) e^{-j2\pi\left(\frac{x\omega_x}{N} + \frac{y\omega_y}{N}\right)}, \tag{13}$$

where ω_x and ω_y are spatial frequencies, x and y are pixels coordinates at image of size $N \times N$, $\varphi(x, y)$ is the image in the spatial domain and the exponential term is the basis function corresponding to each point $\Phi(\omega_x, \omega_y)$ in the Fourier space. The basis functions are sine and cosine waves with increasing frequencies. The term $\Phi(0,0)$ represents the constant component of the image.

Fig. 11 shows the examples of spatial spectra of the shadows of the opaque circle, which is located almost above the center of the screen.

Reducing the radius of the circle from ten to one leads to an increase in the main petal of the spectrum. The value of the amplitude of the spectrum is coded in the software by color (in case of monochrome version by shades of gray) as can be seen in Fig. 11. The invariance of the calculated spectrum to the location of the inspected object on the screen plane makes it possible to apply algorithms for calculating two-dimensional spatial spectra of the shadow image in relation to the required images of some anomalies of pattern in the screening systems of aviation security.

The spectra of two-dimensional shadow images of a parallelepiped (Fig. 7a) and a sphere (Fig. 10) are shown in Figs. 12.

The two-dimensional spatial spectrum must be matched to the required distribution of the radiation intensity of the inspected object $\varphi(x, y)$. In the further processing of visualization data, we find a solution in the frequency space, and then through the inverse Fourier transform, the required distribution $\hat{\varphi}(x, y)$ is calculated. This obtained distribution is put in accordance with the images in the memory of the screening system. The decision to detect the certain object is made after matching the obtained image $\hat{\varphi}(x, y)$ and the mask $\varphi(x, y)$. For further detection, it is necessary to form a 2D-filter with certain spectral characteristics.

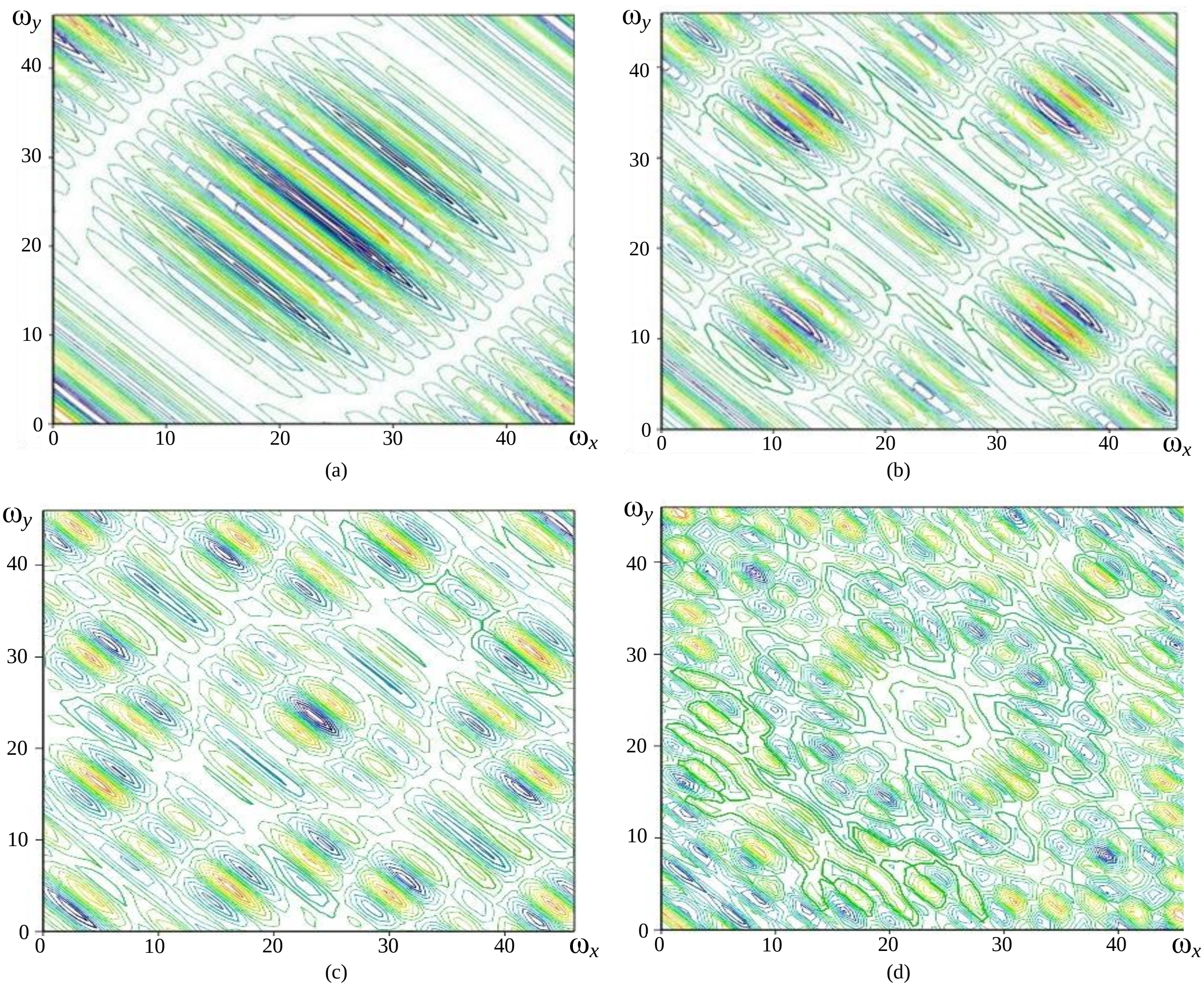

Fig. 11. Two-dimensional spatial spectra of a circle with different radius on a 100×100 plane: a) r = 1; b) r = 3; c) r =5; d) r =10.

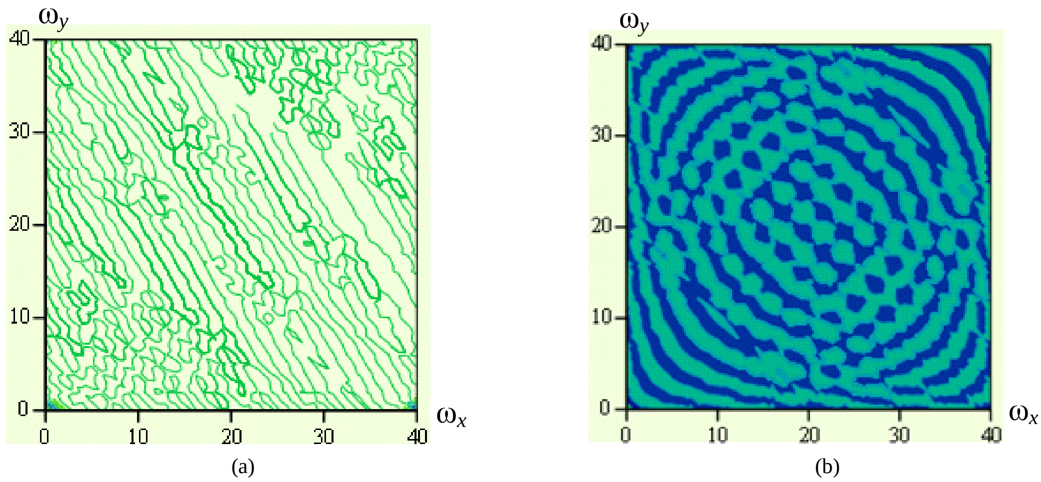

Fig. 12. Spectra of shadow images of: a) parallelepiped; b) sphere.

5. Statistical Simulation of Handgun Recognition Based on Spectral Analysis of Shadow Images

Consider example of synthesis and analysis of spectral method for recognizing prohibited and dangerous objects. In general, it is necessary to use a filter bank in the screening system to detect a given object. In this section, we will consider the features of handgun recognition.

The procedure of synthesis and analysis was performed together with statistical simulation. The flowchart of statistical simulation for spectral method of recognition is shown in Fig. 13.

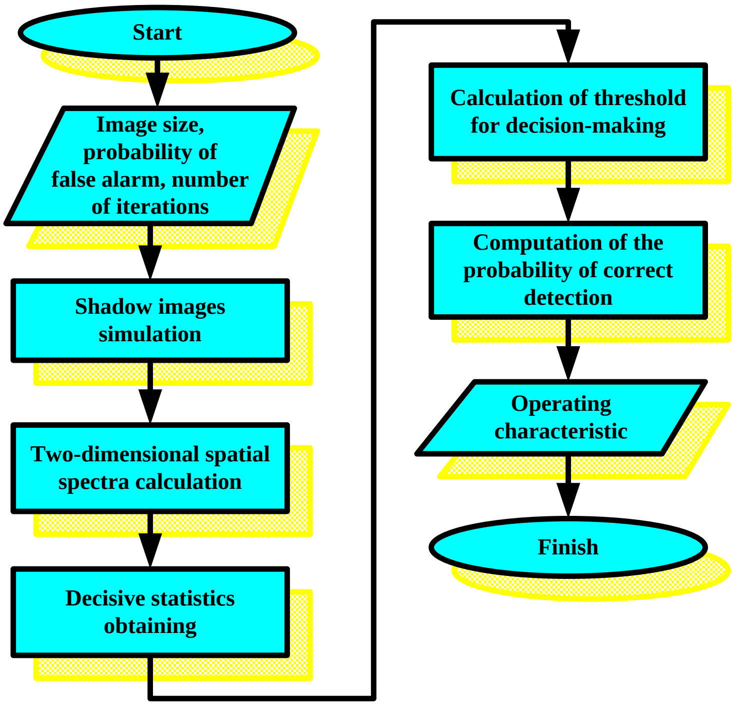

Fig. 13. Flowchart of statistical simulation for spectral method of recognition.

The initial information for simulation is the size of the image, the number of iterations, and the probability of false alarm. To simplify the calculations, an image size of 256×256 pixels was chosen. Each pixel contains information about the color using 512 discrete values. The number of iterations can be arbitrary, but in this research, we chose it equal to 1000. The probability α of false alarm was set to 0.01 level.

The first step of simulation is shadow images obtaining. The shadow of handgun with model $g_3 = f_1 \cup f_3 \cap f_3$ consists of shadows of three objects:

1) parallelepiped (to display the handgun grip);
2) cylinder (to display the barrel of the handgun);
3) cylinder (to display the muzzle of the handgun).

Since the material of the handgun does not pass X-rays, the shadow of the handgun on the image corresponds to the maximum level of response. The shadow of the handgun forms the mask image with size 70×35 pixels.

The shadow image of the handgun is randomly superimposed on the image with size 256×256 pixels. At Therefore, we generate a random location and orientation of the handgun on the image for each iteration of simulation. For each pixel of the image, additive Gaussian noise is formed. The maximum noise amplitude and standard deviation were chosen in accordance with the three-sigma rule with a range of values variation from 0 to 511 (it is equal to 255.5 and standard deviation is 85.167). The noise value was rounded up to an integer value. If generated noise value was out of range from 0 to 511, then it was deleted and a new value was generated. The example of generated shadow image with handgun and additive Gaussian noise is shown in Fig. 14.

The second step of simulation is spatial spectra calculation according to the equation (13). The spatial spectra are determined for:

1) the mask image superimposed on the image with size 256×256 pixels without noise (Fig. 15a),
2) the image with only noise without handgun shadow (Fig. 15b),
3) the image with handgun shadow and additive Gaussian noise (Fig. 16).

The third step of simulation is calculation of decisive statistics. This operation is carried out as convolution of spectra of the mask image superimposed on the image with size 256×256 pixels without noise and the inspected image.

The fourth step of simulation is calculation of threshold of decision-making. This step means determining convolution of spectra of the image with only noise without handgun shadow and the inspected image. The maximums of convolution matrices for each iteration are collected into the sample. As the number of iterations is 1000 and the probability of false alarm is 0.01, then threshold value is tenth value in ordered sample of maximums. In particular simulation, threshold is equal to 20500.

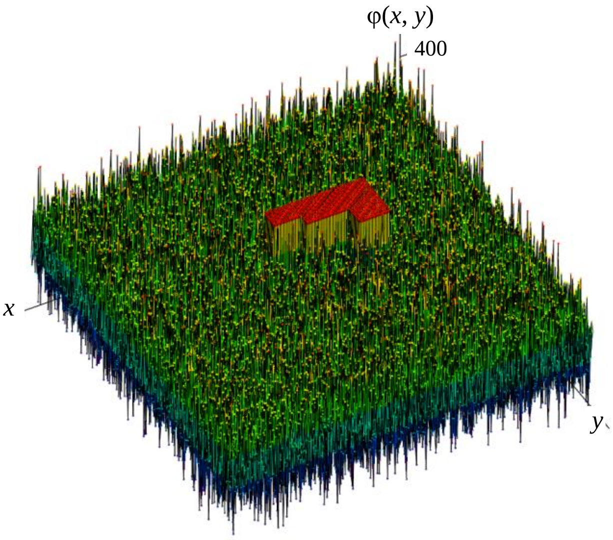

Fig. 14. The example of generated shadow image with handgun and additive Gaussian noise.

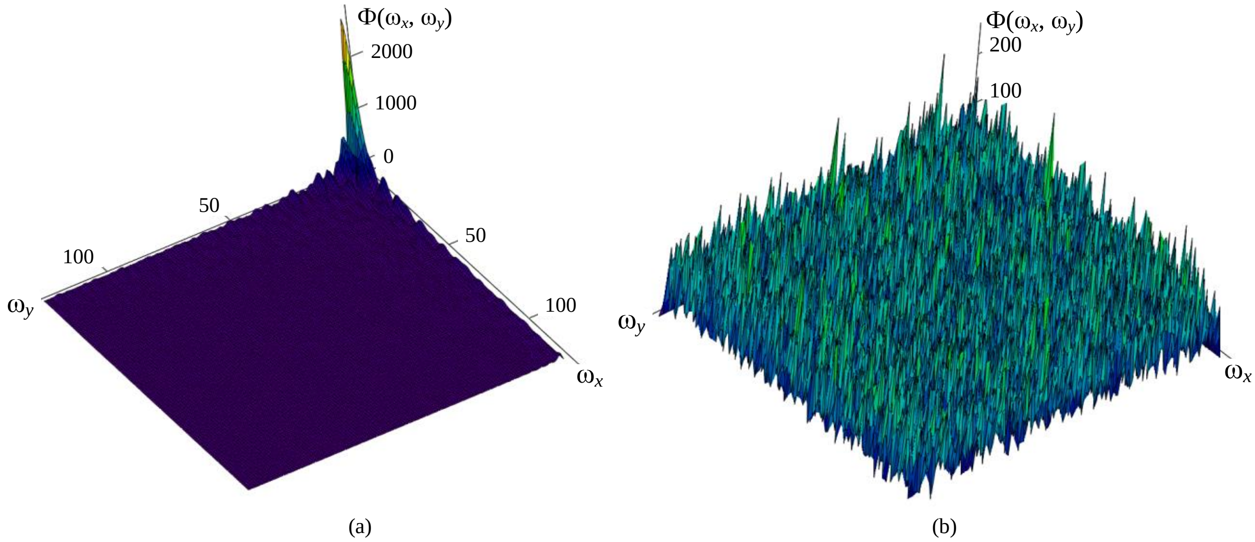

Fig. 15. The spatial spectra of the mask image (a) and Gaussian noise (b).

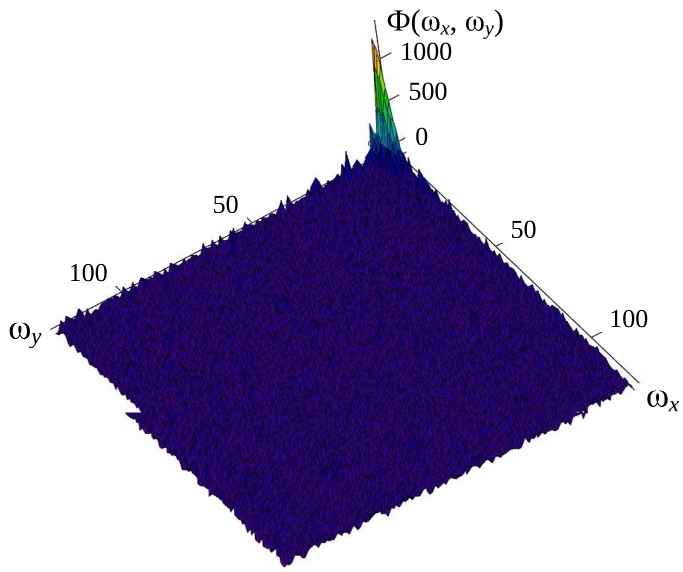

Fig. 16. The spatial spectrum of the image with handgun shadow and noise.

The final step of simulation is computation of the probability of correct detection and operating characteristic plotting. The mentioned probability was determined as ratio of decisions on handgun presence to the number of iterations for different values of signal amplitude and noise. Assumption on different values of signal amplitude is idealized and can be used only for mathematical model, because handgun shadow always has maximum amplitude. Therefore, estimated value of the probability of correct detection was chosen for signal-to-noise ratio equaled to 1. For this simulation the probability of correct detection is equal to 0.99997 (for 100000 iterations). The operating characteristic of handgun detection is shown in Fig. 17.

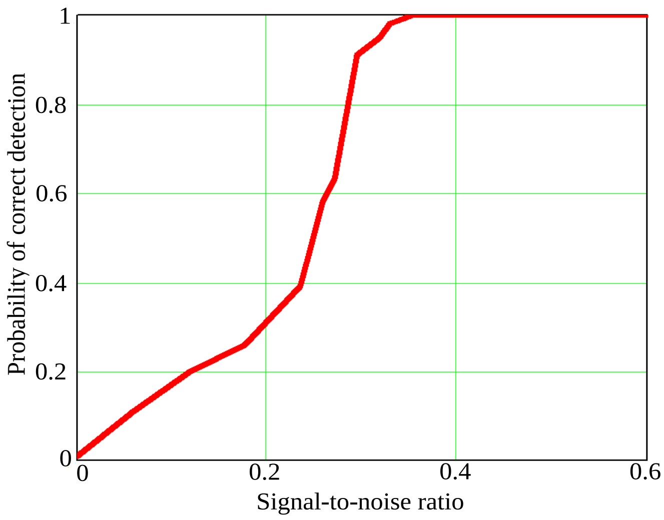

Fig. 17. The operating characteristic of handgun detection.

The simulation shows the following advantages of spectral method of dangerous and prohibited objects recognition:

1. The high efficiency of handgun detection in terms of statistical characteristics (the probability of correct detection is equal to 0.99997, the probability of false alarm is 0.01).
2. Due to the properties of spatial spectrum, the efficiency of handgun detection does not depend on position and location and orientation of the handgun on the inspected image.
3. High time performance and low cost of computing resources.

It should be pointed that simulation results can give slightly better levels of correct detection and false alarm probabilities compared to real images obtained during X-ray screening system operation.

6. Conclusion and Future Research Directions

This article has considered the principles of shadow image processing while screening the baggage using X-ray system. The proposed image processing approach includes the reconstruction of the shadow image for objects of simple shape, the compilation of complex object models from simple objects, and the recognition of dangerous and prohibited objects based on the spectral method.

In comparison with the existing methods, the shadow image reconstruction has been developed based on the basic laws of geometry and Beer-Lambert equation taking into account the chosen technique of scanning. Such approach has given the possibility to determine the shadows using mathematical equations. At the same time, the step-by-step procedure of obtaining the mathematical models of shadow images for parallelepiped and sphere has been shown as an example.

The compilation of complex object models from simple ones has given the ability to collect the shadow images set for real dangerous and prohibited objects with subsequent analysis of their spatial spectra. The spectral method for recognition based on Neyman-Pearson criterion has provided obtaining the required level of the detection probability for X-ray screening system. In particular, the article has presented the features and results of statistical simulation for handgun detection. This simulation has shown that using the spectral method of handgun detection provides high level of the detection probability (equal to 0.99997) at rather low level of the false alarm probability (equal to 0.01).

Unlike known methods, the proposed spectral processing method for recognition has shown simultaneously high probabilistic characteristics of the sought object detection and preferable time performance with low cost of computing resources.

The results of this research can be used for automation of screening processes while using X-ray systems.

Future research directions are associated with:

– collecting the complete database on shadow images for dangerous and prohibited objects in aviation security;
– two-dimensional spatial spectra analysis for masks of dangerous and prohibited objects;
– synthesis of spectral detection algorithms for various dangerous and prohibited objects based on the Neyman-Pearson criterion and the Bayesian approach;
– analysis of efficiency of recognition technique based on shadow images usage, in particular, evaluating probabilities of detection and false alarm at real situations.

Acknowledgment

We would like to express our gratitude to the reviewers for their precise and succinct recommendations that improved the presentation of the materials. In addition, we would like to thank student Cennuo Hu for her assistance and commitment to collecting and analyzing data and references for this paper.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] S. K. Cusick, A. I. Cortes and C. C. Rodrigues, *Commercial Aviation Safety*, Sixth Edition, New York: McGraw-Hill Education, 2012, 696 p.
[2] Doc 9859, *Safety Management Manual*. Montreal: International Civil Aviation Organization, 2018.
[3] M. Chen, Y. Zhang and Y. Chen, "Review on Civil Aviation Safety Investment Research," In 2016 11th International Conference on Reliability, Maintainability and Safety (ICRMS), 2016, pp. 1–5, doi: 10.1109/ICRMS.2016.8050113.
[4] I. Ostroumov and N. Kuzmenko, "Statistical Analysis and Flight Route Extraction from Automatic Dependent Surveillance-Broadcast Data," In 2022 Integrated Communication, Navigation and Surveillance Conference (ICNS),2022, pp. 1–9, doi: 10.1109/ICNS54818.2022.9771515.
[5] I. V. Ostroumov and N. S. Kuzmenko, "Accuracy Estimation of Alternative Positioning in Navigation," In 4th International Conference on Methods and Systems of Navigation and Motion Control, 2016, pp. 291–294, doi:10.1109/MSNMC.2016.7783164.
[6] T. Shmelova, D. Bondarev and Y. Znakovska, "Modeling of the Decision Making by UAV's Operator in Emergency Situations," In 4th International Conference on Methods and Systems of Navigation and Motion Control, 2016, pp. 31–34, doi: 10.1109/MSNMC.2016.7783099.
[7] I. Ostroumov and N. Kuzmenko, "Configuration Analysis of European Navigational Aids Network," In 2021 Integrated Communications Navigation and Surveillance Conference (ICNS), 2021, pp. 1–9, doi: 10.1109/ICNS52807.2021.9441576.
[8] A. I. Nosich, Y. M. Poplavko, D. M. Vavriv and F. J. Yanovsky, "Microwaves in Ukraine," *IEEE Microwave Magazine*, Vol. 3, No. 4, pp. 82–90, Dec. 2002, doi: 10.1109/MMW.2002.1145680.
[9] R. B. Sinitsyn and F. J. Yanovsky, "Acoustic Noise Atmospheric Radar with Nonparametric Copula Based Signal Processing," *Telecommunications and Radio Engineering*, Vol. 71, No. 4, 2012, pp. 327–335, doi: 10.1615/TelecomRadEng.v71.i4.30.
[10] R. B. Sinitsyn and F. J. Yanovsky, "MIMO Radar Copula Ambiguity Function," In European Microwave Week 2012: "Space for Microwaves", EuMW 2012, Conference Proceedings – 9th European Radar Conference, EuRAD 2012, 31 Oct.-2 Nov. 2012, Amsterdam, Netherlands, pp. 146–149.
[11] Annex 17 to the Convention on International Civil Aviation, Security, Montreal: ICAO, 2006.
[12] Wu Wei, "The Application Research of Airport Security Information Management System on the Field of Civil Aviation Security," In International Carnahan Conference on Security Technology, 2009, pp. 277–280, doi: 10.1109/CCST.2009.5335522.
[13] M. Merzbacher and T. Gable, "Applying Data Mining to False Alarm Reduction in an Aviation Explosives Detection System," In 44th Annual 2010 IEEE International Carnahan Conference on Security Technology, 2010, pp. 161–164, doi: 10.1109/CCST.2010.5678738.
[14] D. Li and H. Chen, "Review of Security Inspection Networking System Development in China Airports and Its Trend in the Future," In Proceedings 39th Annual 2005 International Carnahan Conference on Security Technology, 2005, pp. 178–181, doi: 10.1109/CCST.2005.1594825.
[15] R. Lazarick, "Applications of Technology in Airport Access Control," In Proceedings IEEE 35th Annual 2001 International Carnahan Conference on Security Technology, 2001, pp. 85–95, doi: 10.1109/CCST.2001.962817.
[16] A. S. Barry, K. P. Dickie and D. S. Mazel, "Perimeter Security at San Francisco International Airport: Leveraging Independent, Existing Systems to Form an Integrated Solution," In 2009 IEEE Conference on Technologies for Homeland Security, 2009, pp. 35–42, doi: 10.1109/THS.2009.5168012.
[17] S. Gnatyuk, "Critical Aviation Information Systems Cybersecurity," Meeting Security Challenges Through Data Analytics and Decision Support, NATO Science for Peace and Security Series, D: Information and Communication Security. IOS Press Ebooks, 2016, Vol. 47, № 3, pp. 308–316, doi: 10.3233/978-1-61499-716-0-308.
[18] M. Kalimoldayev, S. Tynymbayev, S. Gnatyuk, M. Ibraimov and M. Magzom, "The Device for Multiplying Polynomials Modulo an Irreducible Polynomial," *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, 2019, № 2 (434), pp. 199–205.
[19] M. Zaliskyi, R. Odarchenko, S. Gnatyuk, Y. Petrova and A. Chaplits, "Method of Traffic Monitoring for DDoS Attacks Detection in E-Health Systems and Networks," *CEUR Workshop Proceedings*, 2018, Vol. 2255, pp 193–204.

[20] Z. Hu, R. Odarchenko, S. Gnatyuk, M. Zaliskyi, A. Chaplits, S. Bondar and V. Borovik, "Statistical Techniques for Detecting Cyberattacks on Computer Networks Based on an Analysis of Abnormal Traffic Behavior," *International Journal of Computer Network and Information Security (IJCNIS)*, 2020, Vol. 12, No 6, pp 1–13,doi: 10.5815/ijcnis.2020.06.01.
[21] S. Gnatyuk, B. Akhmetov, V. Kozlovskyi, V. Kinzeryavyy, M. Aleksander and D. Prysiazhnyi, "New Secure Block Cipher for Critical Applications: Design, Implementation, Speed and Security Analysis," *Advances in Intelligent Systems and Computing*, 2020, Vol. 1126, pp. 93–104, doi: 10.1007/978-3-030-39162-1_9.
[22] M. Dyvak, A. Melnyk, A. Kovbasistyi, R. Shevchuk, O. Huhul and V. Tymchyshyn, "Mathematical Modeling of the Estimation Process of Functioning Efficiency Level of Information Web-Resources," In 10th International Conference on Advanced Computer Information Technologies, 2020, pp. 492–496, doi: 10.1109/ACIT49673.2020.9208846.
[23] L. Ji and Y. Mou, "Research on the Feasibility of Application of Millimeter-wave Security Screening Equipment in Civil Aviation," In 2021 IEEE 3rd International Conference on Civil Aviation Safety and Information Technology (ICCASIT), 2021, pp. 71-75, doi: 10.1109/ICCASIT53235.2021.9633747.
[24] O. O. Semenov, *Aviation Security Equipment*, Kyiv: NAU, 2013, 264 p. (in Ukrainian)
[25] D. Anderson, "Optimising Multi-layered Security Screening," *Journal of Transportation Security*, Vol. 14, 2021, pp. 249–273, doi: 10.1007/s12198-021-00237-3.
[26] I. Ostroumov et al., "A Probability Estimation of Aircraft Departures and Arrivals Delays," In: Gervasi O. et al. (eds) "Computational Science and Its Applications – ICCSA 2021," Lecture Notes in Computer Science, Vol. 12950, 2021, pp. 363–377, doi: 10.1007/978-3-030-86960-1_26.
[27] K. Leone, "Security System Throughput Modeling," In Proceedings of 36th Annual 2002 International Carnahan Conference on Security Technology, 2002, pp. 144–150, doi: 10.1109/CCST.2002.1049240.
[28] P. Gupta, Z. Sinno, J. L. Glover, N. G. Paulter and A. C. Bovik, "Predicting Detection Performance on Security X-Ray Images as a Function of Image Quality," *IEEE Transactions on Image Processing*, Vol. 28, No. 7, 2019, pp. 3328–3342, doi: 10.1109/TIP.2019.2896488.
[29] S. Almazroui, W. Wang and G. Zhang, "Imaging Technologies in Aviation Security," *European Journal of Applied Sciences*, Vol. 3, No. 4, 2015, pp. 12–27, doi: 10.14738/aivp.34.1433.
[30] J. Skorupski and P. Uchroński, "A Human Being as a Part of the Security Control System at the Airport," *Procedia Engineering*, Vol. 134, 2016, pp. 291–300, doi: 10.1016/j.proeng.2016.01.010.
[31] O. Solomentsev, M. Zaliskyi, T. Herasymenko and Y. Petrova, "Data Processing Method for Deterioration Detection during Radio Equipment Operation," In 2019 IEEE Microwave Theory and Techniques in Wireless Communications (MTTW), 2019, pp. 1–4, doi: 10.1109/MTTW.2019.8897232.
[32] O. Solomentsev, M. Zaliskyi, O. Shcherbyna and O. Kozhokhina, "Sequential Procedure of Changepoint Analysis During Operational Data Processing," In 2020 IEEE Microwave Theory and Techniques in Wireless Communications (MTTW), 2020, pp. 168–171, doi: 10.1109/MTTW51045.2020.9245068.
[33] V. Cutler and S. Paddock, "Use of Threat Image Projection (TIP) to Enhance Security Performance," In 43rd Annual 2009 International Carnahan Conference on Security Technology, 2009, pp. 46–51, doi: 10.1109/CCST.2009.5335565.
[34] C. C. von Bastian, A. Schwaninger and S. Michel, "The Impact of Color Composition on X-ray Image Interpretation in Aviation Security Screening," In 43rd Annual 2009 International Carnahan Conference on Security Technology, 2009, pp. 201–205, doi: 10.1109/CCST.2009.5335539.
[35] A. V. Goncharenko, "Optimal UAV Maintenance Periodicity Obtained on the Multi-optional Basis," In Proceedings of IEEE 4th International Conference on Actual Problems of UAV Developments, 2017, pp 65–68, doi: 10.1109/APUAVD.2017.8308778.
[36] A. Raza and V. Ulansky, "Optimization of Condition Monitoring Decision Making by the Criterion of Minimum Entropy," *Entropy (Basel)*, Vol. 21, Issue 12, 2019, pp 1193, doi: 10.3390/e21121193.
[37] O. Shcherbyna et al., "Diagnostic Process Efficiency Analysis for Block Diagram of Electric Field Parameters Meter," In IEEE XIIth International Conference on Electronics and Information Technologies (ELIT), 2021, pp. 5–9, doi: 10.1109/ELIT53502.2021.9501136.
[38] O. V. Solomentsev, M. Yu. Zaliskyi, O. V. Zuiev and M. M. Asanov, "Data Processing in Exploitation System of Unmanned Aerial Vehicles Radioelectronic Equipment," In IEEE 2nd International Conference Actual Problems of Unmanned Air Vehicles Developments (APUAVD), 2013, pp. 77–80, doi: 10.1109/APUAVD.2013.6705288.
[39] M. Zaliskyi et al., "Sequential Method of Reliability Parameters Estimation for Radio Equipment," In IEEE XIIth International Conference on Electronics and Information Technologies (ELIT), 2021, pp. 37–40. doi: 10.1109/ELIT53502.2021.9501099.
[40] M. Zaliskyi and O. Solomentsev, "Method of Sequential Estimation of Statistical Distribution Parameters in Control Systems Design," In IEEE 3rd International Conference Methods and Systems of Navigation and Motion Control (MSNMC), 2014, pp. 135–138. doi: 10.1109/MSNMC.2014.6979752.
[41] O. Solomentsev, M. Zaliskyi and O. Zuiev, "Radioelectronic Equipment Availability Factor Models," In Signal Processing Symposium 2013 (SPS 2013), 2013, pp. 1–4. doi: 10.1109/SPS.2013.6623616.
[42] C. Luo, Y. Hao and Z. Tong, "Research on Digital Image Processing Technology and Its Application," In Proceedings of the 2018 8th International Conference on Management, Education and Information (MEICI 2018), 2018, pp. 587–592, doi: 10.2991/meici-18.2018.116.
[43] R. Alberts, *Modeling and Control of Image Processing for Interventional X-Ray*, Eindhoven: Technische Universiteit Eindhoven, 2010, 202 p.
[44] I. Prokopenko, I. Omelchuk and M. Maloyed, "Synthesis of Signal Detection Algorithms under Conditions of Aprioristic Uncertainty," In IEEE Ukrainian Microwave Week, 2020, pp 418–423, doi: 10.1109/UkrMW49653.2020.9252687.
[45] O. Shmatko et al., "Synthesis of the Optimal Algorithm and Structure of Contactless Optical Device for Estimating the Parameters of Statistically Uneven Surfaces," *Radioelectronic and Computer Systems*, No. 4, 2021, pp. 199–213, doi: 10.32620/reks.2021.4.16.

[46] L. Wang, A. Mohammad-Djafari and N. Gac, "X-ray Computed Tomography Simultaneous Image Reconstruction and Contour Detection Using a Hierarchical Markovian Model," In 2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2017, pp. 6070–6074, doi: 10.1109/ICASSP.2017.7953322.

[47] R. Gesick, C. Saritac and C.-C. Hung, "Automatic Image Analysis Process for the Detection of Concealed Weapons," In Proceedings of the 5th Annual Workshop on Cyber Security and Information Intelligence Research Cyber Security and Information Intelligence Challenges and Strategies, 2009, pp. 1–12, doi: 10.1145/1558607.1558630.

[48] V. Riffo and D. Mery, "Automated Detection of Threat Objects Using Adapted Implicit Shape Model," *IEEE Transactions on Systems, Man, and Cybernetics Systems*, Vol. 46, No. 4, 2016, pp. 472–482, doi: 10.1109/TSMC.2015.2439233.

[49] S. Akçay, M. E. Kundegorski, M. Devereux and T. P. Breckon, "Transfer Learning Using Convolutional Neural Networks for Object Classification within X-ray Baggage Security Imagery," In 2016 IEEE International Conference on Image Processing (ICIP), 2016, pp. 1057–1061, doi: 10.1109/ICIP.2016.7532519.

[50] B. Gu, R. Ge, Y. Chen, L. Luo and G. Coatrieux, "Automatic and Robust Object Detection in X-Ray Baggage Inspection Using Deep Convolutional Neural Networks," *IEEE Transactions on Industrial Electronics*, Vol. 68, No. 10, 2021, pp. 10248–10257, doi: 10.1109/TIE.2020.3026285.

[51] Y. F. A. Gaus, N. Bhowmik, S. Akçay, P. M. Guillén-Garcia, J. W. Barker and T. P. Breckon, "Evaluation of a Dual Convolutional Neural Network Architecture for Object-wise Anomaly Detection in Cluttered X-ray Security Imagery," In 2019 International Joint Conference on Neural Networks (IJCNN), 2019, pp. 1–8, doi: 10.1109/IJCNN.2019.8851829.

[52] J. Zhang, X. Song, J. Feng and J. Fei, "X-Ray Image Recognition Based on Improved Mask R-CNN Algorithm," *Mathematical Problems in Engineering*, Vol. 2021, pp. 1–14, doi: 10.1155/2021/6544325.

[53] I. V. Ostroumov, K. Marais and N. S. Kuzmenko, "Aircraft Positioning Using Multiple Distance Measurements and Spline Prediction," *Aviation*, Vol. 26, Issue 1, 2022, pp. 1-10, doi:10.3846/aviation.2022.16589.

[54] I. G. Prokopenko, "Robust Methods and Algorithms of Signal Processing," In 2017 IEEE Microwaves, Radar and Remote Sensing Symposium (MRRS), 2017, pp. 71–74, doi: 10.1109/MRRS.2017.8075029.

[55] Y. Averyanova et al., "Polarimetric-radar Drop Size Evaluation for Wind Speed Estimate Based on Weber Criterion," In Signal Processing Symposium (SPSympo), 2021, pp 17–22, doi: 10.1109/SPSympo51155.2020.9593349.

[56] I. V. Ostroumov, N. S. Kuzmenko and K. Marais, "Optimal Pair of Navigational Aids Selection," In 5th International Conference on Methods and Systems of Navigation and Motion Control, 2018, pp. 32–35, doi: 10.1109/MSNMC.2018.8576293.

[57] Y. Averyanova et al., "Model for Wind-related Phenomena Estimation Using Polarization Characteristics of Microwave Radar Signal," In IEEE 16th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering, 2022, pp. 173–177, doi: 10.1109/TCSET55632.2022.9767049.

[58] V. Volosyuk et al., "Optimal Method for Polarization Selection of Stationary Objects against the Background of the Earth's Surface," *International Journal of Electronics and Telecommunications*, 2022, Vol. 68, No. 1, pp. 83–89. doi: 10.24425/ijet.2022.139852.

[59] S. Zhyla et al., "Statistical Synthesis of Aerospace Radars Structure with Optimal Spatio-temporal Signal Processing, Extended Observation Area and High Spatial Resolution," *Radioelectronic and Computer Systems*, 2022, No. 1 (101), pp. 178–194, doi: 10.32620/reks.2022.1.14.

[60] V. Chikovani, O. Sushchenko and H. Tsiruk, "Redundant Information Processing Techniques Comparison for Differential Vibratory Gyroscope," *Eastern-European Journal of Enterprise Technologies*, 2016, Vol. 4, No 7 (82), pp 45–52, doi: 10.15587/1729-4061.2016.75206.

[61] Yu. Averyanova, A. Averyanov and F. Yanovsky, "The Approach to Estimating Critical Wind Speed in Liquid Precipitation using Radar Polarimetry," In International Conference on Mathematical Methods in Electromagnetic Theory, MMET, 2012, pp. 517–520, doi: 10.1109/MMET.2012.6331259.

[62] F. J. Yanovsky and I. M. Braun, "Models of Scattering on Hailstones in X-band," In First European Radar Conference, EURAD, Amsterdam, Netherlands, 2004, pp. 229–232.

[63] A. K. Shukla, *Medical Imaging Methods: Theory and Applications*. Boca Raton: CRC Press, 2022, 200 p.

[64] J. Hsieh, B. Nett, Z. Yu, K. Sauer, J.-B. Thibault and C. A. Bouman, "Recent Advances in CT Image Reconstruction," *Current Radiology Reports*, Vol. 1, 2013, pp. 39–51, doi: 10.1007/s40134-012-0003-7.

[65] V. Hnatushenko, V. Hnatushenko, V. Kashtan, O. Reuta and I. Udovyk, "Voxel Approach to the Shadow Formation Process in Image Analysis," In 11th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), 2021, pp. 33–36, doi: 10.1109/IDAACS53288.2021.9660909.

[66] B. D. Man and S. Basu, "Distance-driven Projection and Backprojection in Three Dimensions," *Physics in Medicine and Biology*, Vol. 49, No 11, 2004, pp. 2463–2475, doi: 10.1088/0031-9155/49/11/024.

[67] J. A. Fessler, "Statistical Image Reconstruction Methods for Transmission Tomography," In: J. M. Fitzpatrick and M. Sonka (eds), "Handbook of Medical Imaging, Volume 2. Medical Image Processing and Analysis," 2000, pp. 1–70, doi: 10.1117/3.831079.ch1.

[68] J. Jakubek, "Data Processing and Image Reconstruction Methods for Pixel Detectors," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Vol. 576, No 1, 2007, pp. 223–234. doi: 10.1016/j.nima.2007.01.157.

[69] R. K. Schulze, O. Weinheimer, D. D. Brüllmann, F. Röder, B. d'Hoedt and E. Schoemer, "Software for Automated Application of a Reference-based Method for a Posteriori Determination of the Effective Radiographic Imaging Geometry," *Dentomaxillofac Radiology*, Vol. 34, No 4, 2005, pp. 205–211. doi: 10.1259/dmfr/56357032. PMID: 15961593.

Authors' Profiles

Dr. Maksym Zaliskyi is a professor at the National Aviation University. His qualifications are as mentioned D.Sc. (Equipment Operation and Data Processing), PhD (Equipment Operation and Data Processing), M.Sc. (Radio Engineering), B.Sc. (Radio Engineering). He has 14 years of teaching experience and his areas of interest include data processing, equipment operation and reliability analysis. A total number of research publications is 165.

Dr. Olga Shcherbyna is a professor at the National Aviation University. Her qualifications are as mentioned D.Sc. (Radio Engineering and Telecommunication Means), Ph.D. (Radio Engineering Devices and Television Systems), M.Sc. and B.Sc. (both in Radio Engineering) from the National Aviation University, Kyiv, Ukraine. She has 16 years of teaching experience and her areas of interest include antenna systems, microwave devices, electromagnetic compatibility. A total number of research publications is 100.

Dr. Lidiia Tereshchenko is an associate professor at the National Aviation University. Her qualifications are as mentioned Ph.D. (Radio Engineering Devices and Television Systems), M.Sc. (Radio Engineering), B.Sc. (Radio Engineering) from the Kyiv International University of Civil Aviation, Kyiv, Ukraine. She has 17 years of teaching experience and her areas of interest include image processing, radio engineering systems, signal processing, intelligent systems and mathematical modeling. A total number of research publications is 39.

Dr. Alina Osipchuk is an associate professor at the National Aviation University. Her qualifications are as mentioned Ph.D. (Radio Engineering and Telecommunication Means), M.Sc. (Systems of Air Navigation Service), B.Sc. (Aviation and Space Equipment) from the National Aviation University, Kyiv, Ukraine. She has 15 years of teaching experience and her areas of interest include radio engineering systems, signal processing and mathematical modeling. A total number of research publications is 34.

Dr. Olena Zharova is an associate professor at the National Aviation University. Her qualifications are as mentioned Ph.D. (Pedagogics), M.Sc. (Operation of Aircraft Radio Equipment), B.Sc. (Operation of Aircraft Radio Equipment) from the National Aviation University, Kyiv, Ukraine. She has 13 years of teaching experience and her areas of interest include telecommunication and radio systems, data processing and equipment operation. A total number of research publications is 30.

How to cite this paper: Maksym Zaliskyi, Olga Shcherbyna, Lidiia Tereshchenko, Alina Osipchuk, Olena Zharova, "Shadow Image Processing of X-Ray Screening System for Aviation Security", International Journal of Image, Graphics and Signal Processing(IJIGSP), Vol.14, No.6, pp. 26-46, 2022. DOI:10.5815/ijigsp.2022.06.03