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OBJECT DETECTION PERFORMANCE INDICATOR IN VIDEO SUVEILLANCE SYSTEMS

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ABSTRACT

Context. The probability of detecting the object by the operator of the video surveillance system depends on a number of parameters (geometric dimensions of the object of observation, distance to the object of observation, parameters of the video surveillance camera, monitor parameters, etc.).

Objective. The purpose of the article is to develop an indicator of the effectiveness of detecting dynamic objects when evaluating the functioning of video surveillance systems.

Method. An indicator of the effectiveness of object detection when evaluating the functioning of video surveillance systems is proposed. The proposed indicator is expressed in the probability of detection of the object of interest by the *i*-th operator thanks to the person's own visual apparatus or with the help of a software algorithm. This indicator differs from the existing ones by taking into account the parameters of the optical system, the parameters of the information display device (monitor), the number of video surveillance cameras, etc. The developed indicator makes it possible to estimate the probability of detection of an object by a video surveillance system operator thanks to a person's own visual apparatus or with the help of a software algorithm, depending on the distance to such an object.

Results. According to the results of experimental calculations, it has been proven that the effectiveness of the use of video surveillance systems with the use of video analytics functions (using the example of the dynamic object detection algorithm).

Conclusions. The conducted experimental calculations confirmed the efficiency of the proposed mathematical apparatus and allow us to recommend it for use in practice when solving problems of evaluating the effectiveness of the functioning of video surveillance systems.

KEYWORDS: probability, detection, human operator, criterion, efficiency, indicator, task, performance, calculations, mathematical apparatus.

ABBREVIATIONS

VSS is a video surveillance systems;
TTP is a Targeting Task Performance;
CTF is a contrast threshold function;
MTF is a modulating transfer function;
ViBe is a Visual Background Extractor;
NVESD is a Night Vision and Electronic Sensors Directorate.

NOMENCLATURE

P_{op} is a probability of detection of an alarming event by the actual operator of the video surveillance system;
K_{op} is a coefficient of readiness of the VSS operator;
K_{Ψ} is a coefficient of psychophysiological reliability of the VSS operator;
K_{bio} is a coefficient of biological reliability, including functional suitability of VSS operator;
T_0 is a time during which the operator was not at workplace;
T_{oth} is a the time during which the operator was at workplace but did not monitoring the situation;
T is a total operating time of the operator;
P_{TTP} is a probability of object detecting (TTP);
N_{res} is a число пар штрихів, що розміщуються на об'єкті;
E is a емпірично визначена константа;
A_{obj} is a the area of the observed object;
R is a distance to the object;
V is a resolvable cycles across target;
V_{50} is a number of cycles for 50% detection;
$TTPH$ is a horizontal components of TTP;
$TTPV$ is a vertical components of TTP;
$\xi_{\max}$ is a maximum horizontal spatial frequencies at a given contrast;
$\eta_{\max}$ is a maximum vertical spatial frequencies at a given contrast;
$\xi_{\min}$ is a minimum horizontal spatial frequencies at a given contrast;
$\eta_{\min}$ is a minimum vertical spatial frequencies at a given contrast;
C_{obj} is a contrast target relative to background;
$CTFH_{sys}$ is a the CTF of the system for the horizontal plane;
$CTFV_{sys}$ is a the CTF of the system for the vertical plane;
CTF_{eye} is a CTF of the operator's eye;

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MTF_{dys} is a MTF of the display;

MTF_{sys} is a MTF of video surveillance system;

QH is a the noise bandwidth in the horizontal plane;

QV is a the noise bandwidth in the vertical plane;

α is a coefficient of proportionality;

σ is a the root-mean-square value of the display noise;

L is a display brightness;

α is a angle of view of the operator;

h is a linear monitor size;

l is a the distance from the eye to the plane of the monitor;

K_{periph} is a complex coefficient;

P_{alg} is a probability of object detection by a software algorithm;

$P_{op/alg}$ is a probability of detection alarming event (object of interest) by VSS operators using a software algorithm;

$H_{mon\%}$ is a height of the observed object, as a percentage of the height of the monitor;

H_{obj} is a the height of the observed object;

H_{sceny} is a the height of the observed scene;

R_{obj} is a distance to the object (m);

H_{matr} is a the height of the matrix of the VSS camera;

f is a focal length;

Pjonson is a probability of object detection by the VSS operator without use of video analytics algorithms, calculated using the Johnson criteria;

Pttp is a probability of object detection by the VSS operator without use of video analytics algorithms, calculated using success rate of the TTP;

Pobj is a the probability of object detection by the operator video surveillance system using video analytics algorithms, calculated using the proposed indicator.

INTRODUCTION

VSS are the main components of integrated security systems. The main function of VSS is to monitor certain objects. The installation of video analytics functions in such systems, obviously, increases the efficiency of their application. Thus, the urgent task is to study and develop a mathematical apparatus to assess the effectiveness of VSS.

The object of study is the process of evaluating the effectiveness of video surveillance systems.

The subject of study is an indicator of object detection efficiency.

The purpose of the work is to develop an indicator of the effectiveness of detecting dynamic objects when evaluating the functioning of video surveillance systems.

1 PROBLEM STATEMENT

Let's take the raw data: video surveillance cameras (I) function as part of the video surveillance system, operators (J) monitor the situation in the inspection sectors of the specified cameras. It is necessary to find: 1) the probability of detecting the object (alarming event) by the operator using his own visual observation (Pop); the probability of detecting an object (an alarming event) using a software algorithm (Pop/alg).

Accepted assumptions: the psycho-emotional characteristics of the human operators, their fatigue and level of training are not taken into account in the experimental calculations.

2 REVIEW OF THE LITERATURE

The research of a number of scientists is devoted to the study of the effectiveness of the functioning of optoelectronic surveillance systems as a complex technical system. So for example, in article [1] proposed the concept of performance indicators of target tasks by operators. However, these indicators do not take into account the characteristics of the device for receiving optical signals (VSS cameras) and display parameters. Johnson's model provided definitive criteria for calculating the maximum range at which "Detection, Recognition, and Identification" could take place, with a 50% probability of success. (Orientation was also discussed, but this parameter is not used or recognized today) [2]. Nevertheless, Johnson's criterion does not take into account a number of important parameters that also affect the probabilistic performance of the target: the characteristics of the human visual system, lighting characteristics, and so on. Vollmerhausen R. H. [3] described targeting task performance, which takes into account the parameters of the optical system, human visual system, lighting characteristics, etc. In [4] proposed an analytical expression to determine the probability of object recognition in VSS. The methods described in works [3] and [4] do not take into account the level of professional training of the human operator, the level of his fatigue and the number of simultaneously observed video channels. Therefore, it is important to develop an performance indicator of the object detection in VSS.

3 MATERIALS AND METHODS

When computing efficiency of VSS, we can identify a number of criteria that can be divided into the following groups:

– economic criteria (the ratio of the actual cost of the already deployed system with the level of probable losses is estimated);

– functional criteria (assess how the functionality of the system meets the requirements of the security concept, etc.);

– criteria of efficiency (conformity is estimated that the configuration of the deployed video surveillance system will give the chance to reach necessary probabilities of detection of threats).

The effectiveness of detecting an object of interest or alarm in the surveillance sectors of VSS cameras is determined by such indicators as:

– the probability of object detection directly by the operator;

– the probability of object detection by a software algorithm;

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– the probability of object detection by a human operator with the software algorithm.

We use the concept of performance indicators for the targets performance by VSS operator. The probability of detecting an alarming event by the actual people-operators of the video surveillance system can be expressed as:

$$P_{op} = K_{op} \cdot K_{\Psi} \cdot K_{bio}, \tag{1}$$

$$K_{op} = 1 - \frac{T_0 + T_{oth}}{T}. \tag{2}$$

The observation process also depends from many random factors, we used Johnson's criteria [2], [6] to calculate the probability of detection object by the VSS operator. This technique involves comparing the minimum size of the observed object with the number of periods of the dashed measure in which the specified object falls. Johnson compared the observer's ability to distinguish between images of a test measure and his ability to distinguish between objects such as humans and vehicles. The Johnsons method divided the observation tasks into some levels: detection, recognition and identification (see Tab. 1) [7].

This set of data, known as the Johnson's criteria, represents the number of cycles (or pixels in horizontal projection) across a target for an ensemble of observers to have a 50% chance of completing the discrimination task.

Table 1 – Values of Johnson's criteria for performance of tasks by the operator of system of video surveillance (50% probability tasks performance)

Discrimination Level	Cycles on Target	Pixels on Target
Detection	2	3
Recognition	4	6
Identification	6	9

Conversion coefficients are used to obtain other probabilities [8], [9] (see Tab. 2).

Table 2 – Conversion coefficients for the Johnson's criteria

Probability of detection	100	95	80	50	30	10
Conversion coefficient	3	2	1.5	1	0.75	0.5

However, Johnson's criteria does not take into account a number of important parameters that also affect the probabilistic performance of the target: the characteristics of the human visual system, lighting characteristics, and so on. The NVESD laboratory has proposed a Targeting Task Performance. The empirical equation for calculating the probability of object detecting has the form [3], [10]:

$$P_{TTP} = \frac{\left(\frac{N_{res}}{V_{50}}\right)^{E}}{1 + \left(\frac{N_{res}}{V_{50}}\right)^{E}}, \tag{3}$$

$$N_{res} = \frac{\sqrt{A_{obj}} \cdot TTP}{R}, \tag{4}$$

$$E = 1.51 + 0.24 \cdot \frac{V}{V_{50}}, \tag{5}$$

$$TTP = \sqrt{TTPH \cdot TTPV}, \tag{6}$$

$$TTPH = \int_{\xi_{\min}}^{\xi_{\max}} \left[\frac{C_{obj}}{CTFH_{sys}(\xi)}\right]^{1/2} d\xi, \tag{7}$$

$$TTPV = \int_{\eta_{\min}}^{\eta_{\max}} \left[\frac{C_{obj}}{CTFV_{sys}(\eta)}\right]^{1/2} d\eta, \tag{8}$$

$$CTFH_{sys}(\xi) = \frac{CTF_{eye}}{MTF_{dys} \cdot MTF_{sys}} \cdot \left(1 + \frac{\alpha^2 \cdot \sigma^2 \cdot QH \cdot QV}{L^2}\right)^{1/2}, \tag{9}$$

$$CTFV_{sys}(\eta) = \frac{CTF_{eye}}{MTF_{dys} \cdot MTF_{sys}} \cdot \left(1 + \frac{\alpha^2 \cdot \sigma^2 \cdot QH \cdot QV}{L^2}\right)^{1/2}. \tag{10}$$

So, the probability of object detection depends not only on the coefficients of readiness, psychophysiological and biological reliability, but also on such an indicator as the physically possible probability of object detection, which takes into account the parameters of the optical system, human visual system, distance to the object observation, etc. Then the probability of detecting an alarm event (object of interest) by the VSS operator of will take the form:

$$P_{op} = \frac{\left(\frac{N_{res}}{V_{50}}\right)^{E}}{1 + \left(\frac{N_{res}}{V_{50}}\right)^{E}} \cdot K_{op} \cdot K_{\Psi} \cdot K_{bio}. \tag{11}$$

Eq. (11) will be valid for a single-channel VSS. If we use a multi-channel video surveillance system, the probability of detecting an alarm event (object of interest) will decrease as the number of VSS cameras increases. If the operator chooses the tactics of sequential viewing of each video channel, the observation time in seconds for each video channel is about 2 s. [11]. The time of fixation of vision on each video channel is about 0.3 s. [11] Therefore, in this case, the remaining video channels are ignored by the operator. But physiological features of the person allow to observe objects and by means of peripheral sight. The whole zone of human vision can be divided into the following zones: the zone of central vision (5°), the zone of clear vision (up to 30°), the zone

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of peripheral vision (up to 110°) (see Fig. 1). To calculate the angle of view of the operator uses the equation:

$$\alpha = arctg\left(\frac{h}{2l}\right). \qquad (12)$$

Operator angle determines the angle between the lines connecting the extreme points of the monitor (horizontally or vertically) and the operator's eye.

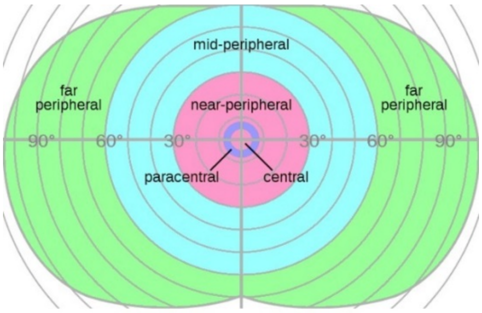

Figure 1 – Zones of human vision [12]

The probability of detecting objects at a distance from the central zone of human vision will decrease. Then, to take into account the number of VSS cameras and the peculiarities of human peripheral vision, we introduce into Eq. (12) a complex coefficient K_{periph}. Then Eq. (11) will look like:

$$P_{op} = \frac{\left(\frac{N_{res}}{V_{50}}\right)^{E}}{1+\left(\frac{N_{res}}{V_{50}}\right)^{E}} \cdot K_{op} \cdot K_{\Psi} \cdot K_{bio} \cdot K_{periph}. \qquad (13)$$

The probability of object detection by a software algorithm depends on the algorithm itself, application conditions, and so on. Let us denote this probability as P_{alg}. However, the detection of an alarm event by a software algorithm is not a result indicator of the whole system, because the algorithm notifies the operator of the VSS about a certain event, and the operator makes a decision.

The probability of detection alarming event (object of interest) by VSS operators using a software algorithm: $P_{op/alg} \le P_{alg}$ and $P_{op/a\lg} \to P_{a\lg}$.

Therefore, the criterion for the effectiveness of object detection, which is expressed in the probability of detecting an alarm event will take the following form:

$$P_{obj} = P_{op} \cdot P_{op/a\lg} + P_{op} \cdot (1 - P_{op/a\lg}) + P_{op/a\lg} \cdot (1 - P_{op}) \,. \qquad (14)$$

4 EXPERIMENTS

A numerical experiment was conducted to verify the adequacy of the proposed performance indicator and comparative analysis of methods for assessing the effectiveness of object detection by VSS operators (Johnson criteria, TTP task success rate) [13].

We consider a conditional software and hardware complex consisting of 8 VSS cameras. Number of VSS operators – one. Surveillance is performed using a monitor with a diagonal of 21 inch. (16 : 9 aspect ratio). Resolution – 1920x1080 px. Monitor width – 46.49 cm. Monitor height – 26.15 cm. The distance from the operator's eye to the monitor is 80 cm. The frame rate is 25 Hz. α – 169.6; σ – 0.02; L – 100 cd/m^2.

Suppose that when placed on the monitor with the parameters of the information windows of the eight video channels, the resolution of each of them will be 480x272 (CIF) (see Fig. 2).

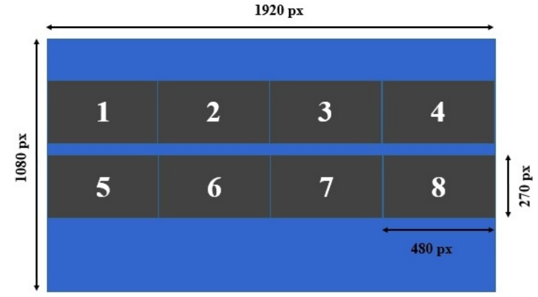

Figure 2 – Example of placing information windows of eight video channels on the monitor screen

VSS cameras of the same type with the basic parameters: 1/3 matrix (4.92 mm x 2.77 mm), focal length – 10 mm.

Object of observation: a person (1.7m x 0.5 m).

Viewing area: horizontal plane – 26 m, vertical plane – 14 m.

The probability distribution function of the correct classification of dynamic objects by software is obtained empirically because of experimental studies of the dynamic object detection algorithm ViBe [14].

To calculate the height of the observed object, as a percentage of the height of the monitor (one of the eight video channels in our experiment), the Eq. [12]:

$$H_{mon\%} = \frac{100\% \cdot H_{obj}}{H_{sceny}}, \qquad (15)$$

$$H_{sceny} = \frac{H_{matr} \cdot R_{obj}}{f}. \qquad (16)$$

The graph of the height of the observed object (as a percentage of the height of the monitor) from the distance to this object (with the above parameters) is shown in Fig. 3.

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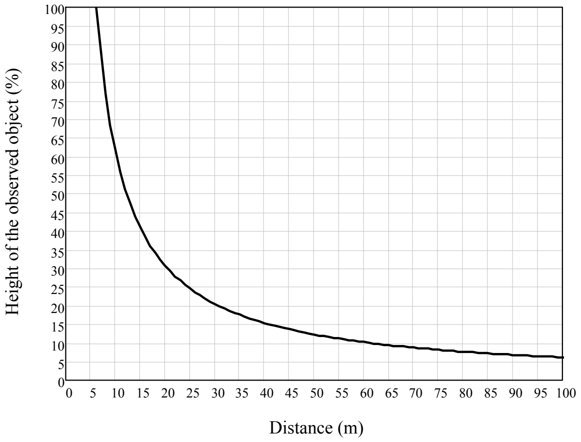

Figure 3 – Graph of the dependence of the height of the observed object (as a percentage of the height of the monitor) on the distance to this object

Johnson's criterion makes it possible to evaluate the effectiveness of the task with a 50% probability, and the use of conversion factors (see Tab. 2) to obtain probabilistic characteristics. The graph of the number of pixels on which the object is displayed (in the horizontal plane) on the distance to this object is shown in Fig. 4.

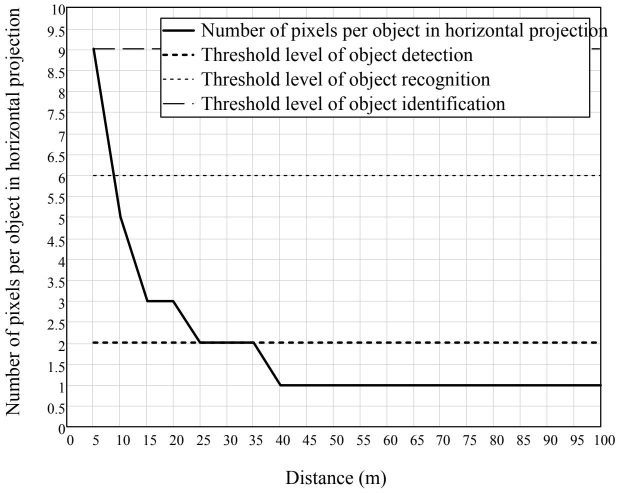

Figure 4 – Graph of calculations of the number of pixels on which the observed object is displayed in the smallest projection (in the horizontal plane)

To perform calculations estimate the probability of detection object by the VSS operator using the success rate of the TTP task (see Eq. 3 and Eq. 14). The CTF of the eye operator is calculated by the formula from [15], [16], MTF of the video surveillance system, MTF of the display are calculated by the Eq. from [3]. The contrast of the target relative to the background C_{obj} is calculated by the formula presented in [15]. The spectral range is equal to 0.5 μm – 1 μm.

Take the values of the coefficients: $K_{op}=1$, $K_{\Psi}=1$, $K_{bio}=1$, $K_{periph}=1$.

5 RESULTS

After modelling the obtained results using the software package MathCad, there was a graphical representation of the function dependence of the probability detection observed object (person) on the observation range (see Fig. 5).

On the Fig. 5: *Pjonson*, *Pttp* calculated using the Johnson criteria (taking into account conversion coefficients (see Tab. 3)) and the success rate of the TTP, respectively. *Pobj* calculated using the proposed indicator (see Eq. 14).

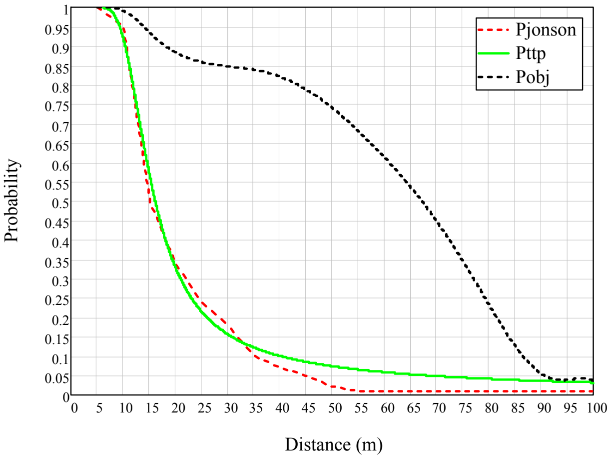

Figure 5 – Object detection probabilities are calculated using the Johnson criterion (*Pjonson*), the success rate of the TTP task (*Pttp*), and the proposed performance indicator of the object detection (*Pobj*) (in the case of use video analytics algorithms)

6 DISCUSSION

After modeling the obtained expressions in the Mathcad software package and using the main characteristics of the conditional software and hardware complex, it is obvious that the probability of detecting an object (person) by the VSS operator depends on a number of parameters (geometric dimensions of the observed object, distance to the object to be observed, parameters of the VSS camera, parameters devices for displaying information (monitor), atmospheric characteristics, visual system of a human operator, psychoemotional characteristics of a human operator, level of fatigue and level of training). In accordance with the recommendations of EN 62676, the object detecting is possible at a distance of 35 m. (see Fig. 4). The probability of object detecting, calculated using the TTP (*Pobj*) task success indicator in the case of using video analytics algorithms (see Fig. 5), depends on the parameters of the software algorithm. The accepted assumptions in experimental calculations do not take into account the psychoemotional characteristics of the human operator, his fatigue and level of training.

CONCLUSIONS

In this article, an indicator for assessing the effectiveness of object detection in VSS was proposed. The results of experimental calculations (see Fig. 5)

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indicate an increase the efficiency of using VSS with video analytics functions (for example we used the algorithm for dynamic objects detection).

The scientific novelty of the obtained results lies in the development of an indicator of the effectiveness of object detection in video surveillance systems. The proposed indicator is expressed in the probability of detection of the object of interest (an alarming event) by the *i*-th operator thanks to the person’s own visual apparatus or with the help of a software algorithm. This indicator differs from the existing ones by taking into account the parameters of the optical system, the parameters of the information display device (monitor), the number of video surveillance cameras, etc.

The practical significance of the obtained results is that the developed indicator makes it possible to estimate the probability of detection of an object by the operator of the video surveillance system thanks to the person’s own visual apparatus or with the help of a software algorithm, depending on the distance to such an object.

Prospects for further research is determined by the software implementation of the proposed criterion, and the analysis of models for assessing the effectiveness of optoelectronic observation systems such as TOD, ORACLE, MTDP, FLIR92, NVThermIP etc.

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ПОКАЗНИК ЕФЕКТИВНОСТІ ВИЯВЛЕННЯ ОБ’ЄКТІВ У СИСТЕМАХ ВІДЕОСПОСТЕРЕЖЕННЯ

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АНОТАЦІЯ

Актуальність. Ймовірність виявлення об’єкта оператором системи відеоспостереження залежить від ряду параметрів (геометричних розмірів об’єкта спостереження, дальності до об’єкта спостереження, параметрів камери відеоспостереження, параметрів монітору тощо.

Метод. Запропоновано показник ефективності виявлення об’єктів при оцінці функціонування систем відеоспостереження. Запропонований показник виражається у ймовірності виявлення об’єкту інтересу оператором завдяки власному зоровому апарату людини чи за допомогою програмного алгоритму. Вказаний показник відрізняється від існуючих врахуванням параметрів оптичної системи, параметрів пристрою відображення інформації (монітору), кількості камер відеоспостереження тощо. Розроблений показник дає можливість оцінити ймовірність виявлення об’єкта оператором системи відеоспостереження завдяки власному зоровому апарату людини чи за допомогою програмного алгоритму, в залежності від відстані до такого об’єкта.

Результати. За результатами експериментальних розрахунків доведено підвищення ефективності застосування систем відеоспостереження із застосуванням функцій відеоаналітики (на прикладі алгоритму виявлення динамічних об’єктів).

Висновки. Проведені експериментальні розрахунки підтвердили працездатність запропонованого математичного апарату і дозволяють рекомендувати його для використання на практиці при вирішенні задач з оцінки ефективності функціонування систем відеоспостереження.

КЛЮЧОВІ СЛОВА: ймовірність, виявлення, людина-оператор, критерій, ефективність, показник, завдання, продуктивність, розрахунки, математичний апарат.

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