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DETERMINATION OF ACCUMULATING PROBABILITY FOR NORMAL DISTRIBUTIONS OF RANGE AND DETECTION EFFICIENCY OF SHORT RANGE WIRELESS DEVICES

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ABSTRACT
The article considers determination of efficiency of extended objects detection by short-range radio detection devices and, in particular, one of their versions - security radio devices. It has been shown that ability of the security devices and systems to detect objects is characterized by a field of instantaneous probability density and a field of accumulating probability of detection, which can serve as a measure of efficiency of these systems and devices. Concepts of instantaneous probabilities of object detection are entered; their interrelations are shown. Expressions for normal and truncated normal distribution of the operation range of the detection devices, as well as expressions for determining the accumulating probability of detection are obtained. Expressions for the determination of the accumulating probabilities when operation range distribution of detection devices submits to normal and truncated normal distribution are given. Use of function of instrumental contact establishing for a quantitative estimation of detection devices efficiency is proved. The article presents expressions for typical object detection cases using the function of instrumental contact establishing.

Keywords: short range wireless device, accumulating probability of detection, normal distribution, truncated normal distribution, range distribution law, detection efficiency.

INTRODUCTION
Ensuring safety both in global, and in local aspects stands in a row of key tasks which can be solved, first of all, by using modern technology. Short-range radio detection devices and systems became considerably spread among such technical means [8], [14]. Such systems and devices along with general questions that are characteristic for creation of all radio engineering systems have a number of specific features associated with small remoteness of their send-receive antennas from as a rule extended detected objects. Locality of detection area means creation of devices with high resolution that, in turn, requires using wideband probing signals [11], [13].

Currently, security radio devices (SRD) [9] that are a kind of short-range radio detection devices (SRRDD) are widely used for surveillance, protection and security of open and closed territories in a variety of alarm systems [10]. In these cases, they are also often referred to as security alarm radio devices (SARD). The main feature of such security devices is use of radar principles for detection of object.

State of the problem in this area is characterized by following main achievements. General theoretical questions of construction and operation of short-range radio engineering systems are considered [6]. Probabilistic hypotheses describing such systems are proposed [20]. Basic functional block diagram for one- and two-channel SRD are developed [18].

SRD can be referred [1] to the short-range radio systems, and must be characterized by other features than those which were introduced in theory of long-range radio systems. So, if they realized principles of radar, it should take into account specific features of short-range such as those associated with extended nature of the object, with comparability the range and geometric dimensions of the object, with multipath nature of signal reflections from such objects, and so on. Analysis of these features of SRD has been reflected in a number of previous works of the authors, for example [3], [7], and other authors [12], [16], [18].

Solving the problem of creating and theoretical analysis of any SRD is reduced to solution of several particular tasks among which we mention two, directly connected to each other:

- development and evaluation of efficiency measures of SRD for open spaces taking into account extended nature of the detected objects, continuously changing distance, various instantaneous detection probability laws;
- estimation of efficiency of radio detection devices and, in particular, SRD in conditions of a priori uncertainty about position of the object and its motion parameters, methods and approaches development to the technical implementation of such devices adaptation.

Previously, the authors considered a number of issues related to the designated tasks [4], [5], but questions of SRD efficiency estimation to date have not been studied. However, evaluation of the efficiency of object detection is quite important, because it allows optimizing the use of SRD and improving economic performance of the system. Further we will discuss this issue in more detail.

DEFINITION OF ACCUMULATING PROBABILITY OF DETECTION FOR NORMAL AND TRUNCATED NORMAL DISTRIBUTIONS OF THE RANGE

Ability of security systems and devices to detect objects can be described by field of instantaneous probability density and by field of accumulating probability of detection [15], which may serve as a measure of the efficiency of these devices and systems.

Thus it is necessary to distinguish that at single observation instantaneous (elementary) probability of object detection at this range by one instant supervision g is used; and under continuous observation – instantaneous (elementary) probability of object detection γdt within a very short time interval dt. We will note that the value γ is intensity (instantaneous probability density) of number of detections.

The considered characteristics [1] are statistical, that is can be found from experiment by following formulas

$$g = 1/\bar{n}\,;\ \gamma = 1/\bar{t}\,,$$

where $\bar{n}$ – expected value of observations n, that provides object detection by means of SRD; $\bar{t}$ – expected value of time t, that provides object detection since the start of the detection system (device).

Using the values of g and γ for the quantitative efficiency characteristic of security devices as detection devices is provided with possibility to determine in practice statistical distributions of the detection range of objects and to determine on their basis dependences $g(R)$ and $\gamma(R)$.

Between these characteristics there is a certain relationship [1], which is expressed by following formula:

$$g = 1 - \exp(-\gamma T)\,,$$

where T – survey period of the detection device.

The efficiency of process of contact establishing with the object for a particular time can be estimated by accumulating (increasing) probability of the object detection [1].

Each point in the plane corresponds to quite certain values of the instantaneous probability density and accumulating probability of detection [6]. For detection system consisting of fixed devices it is possible to construct a statistical field, which will be represented by lines of equal instantaneous probability density of detection or by lines of equal accumulating probabilities of detection.

Consider situation where the range distribution of the detection devices that form defense line, submits normal (ND) or truncated normal (TND) distribution, for which:

- in case of Gaussian distribution

$$W_{ND}(R) = \left(\delta\sqrt{2\pi}\right)^{-1} \cdot \exp\left\{-(R-m)^2/2\delta^2\right\}; \quad (1)$$

$$P_{ND}(R) = \left(\delta\sqrt{2\pi}\right)^{-1} \int_R^{\infty} \exp\left\{-(R-m)^2/2\delta^2\right\} dR = 0,5\left[1 - \Phi\left\{(R-m)/\delta\sqrt{2}\right\}\right]; \quad (2)$$

– in case of truncated Gaussian distribution

$$W_{TND}(R) = \left(\delta\sqrt{2\pi}\right)^{-1} \cdot \exp\left\{-(R-m)^2/2\delta^2\right\} \times \left\{0,5\left[1 - \Phi\left\{(R-m)/\delta\sqrt{2}\right\}\right]\right\}^{-1}; \quad (3)$$

$$P_{TND}(R) = \left[1 + \Phi\left\{(R-m)/\delta\sqrt{2}\right\}\right] / \left[1 + \Phi\left\{m/\delta\sqrt{2}\right\}\right]. \quad (4)$$

To simplify the expressions (1)–(4) are designated: the expected value $m = m_R$; the variance of the probability density function (PDF) $\delta = \delta_R$; Φ – Gauss error function.

For known laws of range distribution of detection devices [1] estimation of the expected probability of instrumental contact establishing is reduced to determining the accumulating detection probability $P(t)$ based on the function $\gamma = \gamma(t)$ calculated taking into account the characteristics of these laws and nature of object motion:

$$P(t) = 1 - \exp\left[-\int_0^t \gamma(t)\,dt\right]. \quad (5)$$

Ceteris paribus SRD ability to detect the object is different for different points of device operation area; it usually increases with the decreasing distance to the object, and it decreases with the increasing distance, i.e. there is dependence, which is the law of the SRD range distribution

$$\gamma = \gamma(R),$$

on the basis of which for known nature of object movement it is possible to determine the law of instrumental contact establishing as function of t, that is,

$$\gamma = \gamma(t).$$

Using the $\gamma(t)$ function for quantitative characteristic of detection devices efficiency is caused by practice possibility of determining of the statistical distributions of objects detection range and identifications on their basis of dependence $\gamma(R)$ for all kinds of typical detection conditions

$$\gamma(R) = W(R)\bar{V} / \left[1 - P(R)\right],$$

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where $W(R)$ - probability density function, in this case characterizing the differential law of range distribution; $1 - P(R) = F(R)$ - distribution function characterizing the integral law of undetection distance distribution; $P(R)$ – distribution function characterizing the integral law of detection distance distribution; $\bar{V}$ - average object movement speed for which it was obtained statistics determining the law of range distribution.

Substituting the expressions for the distribution laws, we find the range of the detection devices for normal and truncated normal distribution

$$\gamma(R)_{ND} = \left[N(m,\delta^2) \Big/ 0,5\left(1+\Phi\{(R-m)/\delta\sqrt{2}\}\right)\right]\bar{V}; \quad (6)$$

$$\gamma(R)_{TND} = \left(\frac{N(m,\delta^2)}{0,5\left[\Phi\left\{m/\delta\sqrt{2}\right\}+\Phi\left\{(R-m)/\delta\sqrt{2}\right\}\right]} \right)\bar{V}. \quad (7)$$

Function $\gamma(t)$ can be obtained by substituting into expression $\gamma(R)$ the law of change of distance R in time at the movement of object relative to the detecting device. The most typical case is when the object moves with a constant speed, having the course parameter P other than zero (Figure 1). In this case, the rate of change of distance between the object and the observer (detection device) during time of detection doesn't remain constant [2].

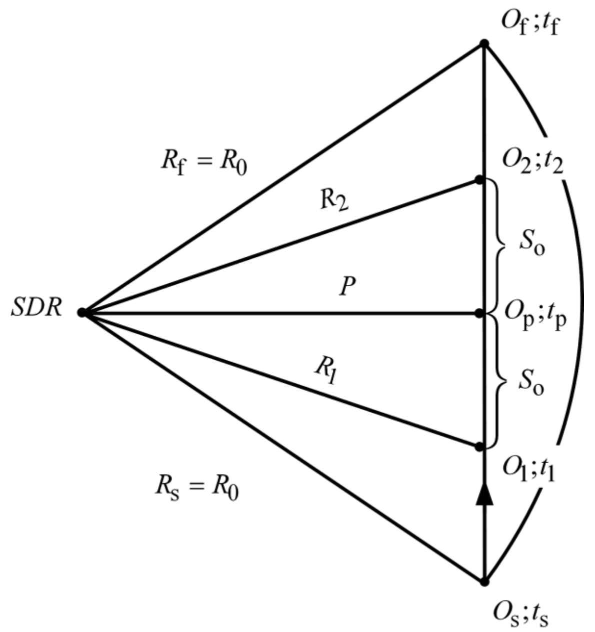

Figure-1. Object movement with nonzero course parameter.

Let the object which was initially at point O_1 (at a distance R_1 from the detection device) is moved at a speed V_o, with the course parameter P. Thus movement of object from the point O_1 to a point O_p occurs for a time

$$t' = t_p - t_1 = \left(R_1^2 - P^2\right)^{0,5} / V_o .$$

Equation of the object movement will be

$$R^2 = P^2 + V_o^2 (t_p - t)^2 ,$$

or

$$R = \left(P^2 + V_o^2 (t_p - t)^2\right)^{0,5} . \quad (8)$$

Timing will be carried from the moment t_s - when the object enters the detection area at point O_s and to the moment $t_f = 2t_p$ - when leaves the area at point O_f.

If we substitute the law of distance change (8) into expressions (6) and (7) instead of R, we obtain expressions for determining the $\gamma(t)_{ND}$ and $\gamma(t)_{TND}$, after substitution which into (5) we obtain the expression for $P(t)_{ND}$ and $P(t)_{TND}$:

THE METHOD OF DETERMINING EXPECTED PROBABILITY OF DETECTION MOVING IN CONTROL ZONE OF OBJECT

Introduced relations are valid for one detection device in security system. However, in many practically important cases the considered defense line is constructed in such a way that detection can occur by two or more SRD. In particular, this will be true if object detection occurred by turnstile or area types SRD. In this case, such a detection system with a probabilistic point of view can be described by means of field of accumulating probability of detection or integral distribution curve total probability of detection $P_n(t)$ for the total length of the defense line.

Each detecting device operates independently of the other. Operation independence is understood in the sense that the detection of the object entering the operation area of a single device does not affect the object detection probability by another device.

Decision about detection is adopted if signal is received from at least one detection device. Therefore it is natural to speak about accumulating probability of detection at least of one security device from n participating in the object detection

$$P_n(t) = 1 - \prod_{i=1}^{n}\left[1 - P_i(t)\right], \quad (9)$$

where n – number of security devices participating in the object detection; $P_i(t)$ – accumulating probability of object detection by security system as a whole.

Substituting in the expression (9) to determine the expression of $P(t)_{ND}$ or $P(t)_{TND}$, we obtain an expression for finding the total accumulating probability of object detection.

The proposed technique gives the possibility in principle to estimate the expected detection probability of any moving object in any course of its movement. However, as a rule, the most interesting possibility is estimating of generalized (integral) characteristics of the object detection efficiency when it breaks the defense line over the shortest distance, i.e. for situation of its movement by courses, perpendicular to defense line.

This technique allows calculating and constructing even more general and universal characteristic of object detection efficiency by defense line, represented in the form of a field of series of equipotential curves equal total detection probabilities depending on depth of object penetration into a detection area.

$$P(t)_{ND} = 1 - \exp\left\{ -\int_0^t \left\{ N\left(m,\delta^2\right) \Big/ 0,5\left[1 + \Phi\left\{\left[\left(P^2 + V_o\left(t_p - t\right)^2\right)^{0,5} - m\right] \Big/ \delta\sqrt{2}\right\}\right]\right\} \bar{V} dt \right\};$$

$$P(t)_{TND} = 1 - \exp\left\{ -\int_0^t \left\{ N\left(m,\delta^2\right) \Big/ 0,5\left[\Phi\left(m/\delta\sqrt{2}\right) + \Phi\left\{\left[\left(P^2 + V_o\left(t_p - t\right)^2\right)^{0,5} - m\right] \Big/ \delta\sqrt{2}\right\}\right]\right\} \bar{V} dt \right\}.$$

At the fixed speed of object of V_o, setting various times t and determining for them final probability $P_n\{t\}$ and deepening $\gamma = V_o t$, it is possible to construct field of the integrated accumulating probability of objects by SDR.

Really, as it was already noted, the accumulating probability of detection is so called because its change happens with time only upward (from 0 to 1). It is clear that when the object moves in SRD operation area each time there will corresponds a certain value of the expected detection probability.

CONCLUSIONS

Thus for the first time expressions for normal and truncated normal distribution of the operation range of the security detection devices, as well as expressions for determining the accumulating probability of detection for these laws are obtained.

A technique is offered that allows estimating the expected detection probability of any object moving within the security system detection area at any point in the detection space. The technique allows calculating the universal efficiency characteristics of object detection at the defense line represented in the form of field of equipotential curve series, equal total object detection probabilities depending on depth of its penetration into a detection area.

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