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MODELS OF FALSE AND CORRECT DETECTION OF INFORMATION LEAKAGE SIGNALS FROM MONITOR SCREENS BY A SPECIALIZED TECHNICAL MEANS OF ENEMY INTELLIGENCE

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Abstract. *The calculation expressions for the probability of false detection of a leakage signal, taking into account the discrete representation of time in the models of detection of side radiation signals from static images on the monitor screen on liquid crystal structures by a specialised technical means of enemy intelligence, which implements an asymptotically optimal joint algorithm for detecting side radiation signals and estimating the duration of the image on the monitor screen, are refined. For this purpose, a large independent array of noise was generated in the Mathcad software environment, and the process of false signal detection by a specialised enemy intelligence vehicle was modelled in several Excel workbooks under conditions of a priori uncertainty about the duration of a static image on the monitor screen.*

Keywords: side electromagnetic radiation and targeting, Neumann-Pearson criterion, probability of false alarm, probability of signal miss

MODELE FAŁSZYWEGO I POPRAWNEGO WYKRYWANIA SYGNAŁÓW WYCIEKU INFORMACJI Z EKRANÓW MONITORÓW PRZEZ WYSPECJALIZOWANE ŚRODKI TECHNICZNE WROGIEGO WYWIADU

Streszczenie*. Określono wyrażenia obliczeniowe dla prawdopodobieństw fałszywego wykrycia sygnału wycieku, biorąc pod uwagę dyskretną reprezentację czasu w modelach wykrywania sygnałów promieniowania bocznego ze statycznych obrazów na ekranie monitora na strukturach ciekłokrystalicznych przez wyspecjalizowane środki techniczne rozpoznania wroga, które implementują asymptotycznie optymalny wspólny algorytm wykrywania sygnałów promieniowania bocznego i szacowania czasu trwania obrazu na ekranie monitora. W tym celu w środowisku oprogramowania Mathcad wygenerowano dużą niezależną tablicę szumów, a proces wykrywania fałszywych sygnałów przez wyspecjalizowane środki techniczne rozpoznania przeciwnika zamodelowano w kilku skoroszytach środowiska oprogramowania Excel, w warunkach niepewności a priori co do czasu trwania statycznego obrazu na ekranie monitora.*

Słowa kluczowe: promieniowanie elektromagnetyczne i przesłuchy, kryterium Neumanna-Pearsona, prawdopodobieństwo fałszywego alarmu, prawdopodobieństwo braku sygnału

Introduction

In [9], the asymptotically optimal algorithm of processing side radiation signals (SR) from monitor screens using liquid-crystal structures (LCS) is synthesized, which is used in modern specialized technical means of enemy intelligence (STMEI), and in [10], the probability of false alarm for STMEI is found:

$$\alpha = 1 - \left[2F\left(\sqrt{h^*}\right) - 1\right] \cdot \left[\frac{T_{a0\max}}{T_{a0\min}}\right]^{-\sqrt{\frac{2h^*}{\pi}} \frac{\exp\left(-\frac{h^*}{2}\right)}{\left[2F\left(\sqrt{h^*}\right)-1\right]}}, \; h^* \geq 0 \quad (1)$$

$h^* = \sqrt{h/K}$ reduced threshold, h – detection threshold, K – number of information harmonics detected by STMEI, $T_{a0\min}, T_{a0\max}$ – lower and upper limits of the a priori interval of values of the unchanged image on the monitor screen, $F(x)$ – distribution function of a Gaussian random variable.

For a monitor with a period of follow-up of the frame scan of the monitor screen on the LCS $T_f = 1/60$ Hz, the STMEI perceives and optimally processes $K \approx 3.3 \cdot 10^7$ of the spectral components of the information leakage signal [1–3], and to model the process of false detection at time intervals $t \in [0, T_a]$, $T_a \leq T_{a0\max}$:

- the likelihood ratio is calculated

$$L(T_{a0}) = \frac{4T_d^2}{N_0 T_{a0}} \sum_{k=1}^{K} \left[\left(\sum_{i=1}^{\mathrm{ceil}(T_{a0}/T_d)} n_i \cos\left(\frac{2\pi k T_d i}{T_f}\right) \right)^2 + \left(\sum_{i=1}^{\mathrm{ceil}(T_{a0}/T_d)} n_i \sin\left(\frac{2\pi k T_d i}{T_f}\right) \right)^2 \right] \quad (2)$$

for $T_{a0\min} \leq T_{a0} < T_{a0\max}$, where $\mathrm{ceil}(x)$ – the integer part of x, T_d – time interval of the process discretisation, n_i – discrete samples of white Gaussian noise (WGN) with one-sided spectral power density N_0 [4, 7];

- the absolute maximum is found (2) for $T_{a0\min} \leq T_{a0} < T_{a0\max}$;
- the distribution of the absolute maximum is found, which is an indicator related to the quality of detection of SR signals with STMEI.

1. Formulation of the modelling task

The task is to verify the reliability of the calculations according to (1) when $T_{a0\max}/T_{a0\min} > 1$, since the reliability $T_{a0\max}/T_{a0\min} = 1$ of the calculations was proved in [5]. For the false alarm probability α, the number of independent model tests n must satisfy the inequation $n > 1/\alpha$. In addition, since the interval T_d actually determines in the model the time of emission of one pixel of information from the monitor screen for a frame on the monitor screen consisting of v lines of w pixels each, modelling the process of false detection of one frame will require $w \cdot v \cdot n$ counts of the WGN (excluding the time for the transmission of line synchronisation pulses) [6], and for $T_{a0} > T_f$, excluding the time for the transmission of frame synchronisation pulses, the inequation for the number of WGNs counts in the model must be satisfied:

$$N > \frac{w \cdot v \cdot T_{a0\min}}{\alpha T_f}. \quad (3)$$

Since for further modelling of the correct detection processes, it is necessary to step T_d through all the true values of the duration of the unchanged image T_{a0} from $T_{a0\min}$ to $T_{a0\max}$, we can present (3) as an expression for calculating the minimum required number of independent samples of the WGN when modelling the process of false detection of the SR [4], if instead of $T_{a0\min}$ we take into account the value $T_{a0\max}$:

$$N_{\min} = \frac{w \cdot v \cdot T_{a0\max}}{\alpha T_f} \tag{4}$$

Taking into account (4) for T_f = 1/60 Hz, $T_{a0\max} / T_f$ = 1200 (twenty seconds of maximum unchanged image on the monitor screen), w = 800, v = 768, α = 0.01, the minimum size of the WGN array for adequate modelling will be $N_{\min} = 7.37 \cdot 10^{10}$. Obviously, in order to build models for studying false and false-pass of the SR signal, it is necessary to use professional programs for processing arrays of information in C++ or C sharp programming languages [8]. However, we will limit ourselves to using the Mathcad software environment to generate the initial independent noise array, and process the information in several Excel workbooks, which, unfortunately, will lead to significant time losses, but will allow for a simple statistical control of each array of information obtained during processing.

For the WGN data set N = 15000 and the emission time of one pixel Δt, a sample of can be obtained from n = 100 during the false alarm simulation according to (2), when $T_{a0\min} = 100T_d$ and $T_{a0\max} = 150T_d$. The simulation results are shown in Fig. 1 as black triangles, and for comparison, the solid line in Fig. 1 are the results of calculations made in accordance with (1). In addition, the grey triangles show the modelling results for $T_{a0\min} = 10T_d$ and $T_{a0\max} = 15T_d$, which, are although more statistically robust (the number of independent trials is increased tenfold), will lead to a greater discrepancy between theory and practice.

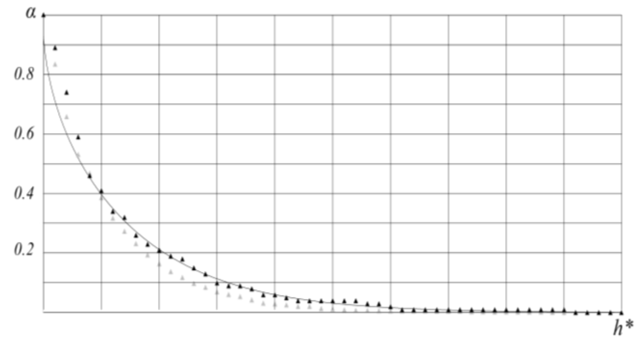

Fig. 1. Dependence of the probability of false alarm on the given detection threshold of the receiver of a specialized technical means of enemy intelligence

It can be assumed that the calculated expression (1) is correct when T_d is decreasing, since the black triangles will more closely match the calculated curve (except for small values h^*). Expression (1) may well coincide with the calculations based on model (2) when $T_d \to 0$. However, to prove this, it is necessary to represent the integrals by infinite sums, which would require an infinite number of tests and is not feasible. Therefore, it is more correct to find calculated expressions that would be correct for any finite T_d, including and when $T_d \to 0$.

Objective: to find an analogous (1) calculation expression for the probability of false detection and the probability of correct detection by an asymptotically optimal algorithm for processing the SR signals from the monitor screens on the LCS, taking into account the representation of continuous processes by their discrete counts with a discretisation period T_d, for $T_{a0\max} / T_{a0\min} > 1$ and $T_{a0\min} \le T_{a0} < T_{a0\max}$, and to confirm the found expressions by simulation.

2. Distribution of the absolute maximum taking into account discrete time in the models

Distribution of the absolute maximum (DAM) of a differentiated random process $\xi(t)$ is equal to:

$$F_0(h,t_2) = F(h,t_1)\exp\left(-\int_{t_1}^{t_2} \frac{\mu(h,t)}{F(h,t)} dt\right) \tag{5}$$

$F(h,t)$ – the distribution of the process at the moment of time t, $\mu(h,t)$ – intensity of the process crossing a fixed level h from the bottom to the top at the moment of time t:

$$\mu(h,t) = \int_0^\infty y w_2(h,y,t)\, dy \tag{6}$$

where $w_2(x,y,t)$ – the joint probability density of the distribution of the process and its derivative at the same time t.

Expression (1) is a special case of expression (5), but, as we can see, the calculations according to (1) are not confirmed by modelling. The fact is that continuous processes $\xi(t)$ in models are represented by their discrete sequences (see Fig. 2). It is necessary to find an analogue of expression (5), taking into account the discretisation of the process with a two-dimensional probability density $w_\xi(x_1,x_2,t_1,t_2)$.

In this case, as was first done by Rice for processes, we will set the intensity (6) in the form of a limit

$$\mu(h,t) = \lim_{T_d \to 0} \mu_+(T_d)$$

where:

$$\mu_+(T_d) = \frac{P_+(T_d)}{T_d}, \tag{7}$$

$P_+(T_d)$ – probabilities of at least one crossing of a fixed level h from the bottom to the top during the discretisation period of the process T_d.

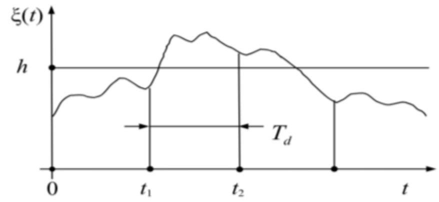

Fig. 2. Intensity of level crossing by discrete counts of a random process

In our case, for the sequence obtained by discretisation of a continuous process $\xi(t)$, the probability $P_+(T_d)$ can be represented as

$$P_+(T_d) = \int_{-\infty}^{h} dx_1 \int_h^\infty w_\xi(x_1,x_2,t_1,t_1+T_d)\, dx_2 \tag{8}$$

and substituting (8) into (7) allows us to obtain an expression for the desired intensity of threshold crossing h by discrete counts of the process $\xi(t)$:

$$\mu_+(T_d) = \frac{1}{T_d} \int_{-\infty}^{h} dx_1 \int_h^\infty w_\xi(x_1,x_2,t_1,t_1+T_d)\, dx_2 \tag{9}$$

Taking into account (9) and the discrete time $t_N = NT_d$, for the upper time index $N_{a0\max} = \operatorname{ceil}\left(T_{a0\max} / T_d\right)$, the analogue of the DAM of a continuous process (5) of the DAM of a random sequence can be given as:

$$F_0\left(h, N_{a0\max}T_d\right) = F\left(h, N_{a0\min}T_d\right) \times$$
$$\times \exp\left(-\sum_{N=N_{a0\min}}^{N_{a0\max}-1} \frac{\int\limits_{-\infty}^{h} dx_1 \int\limits_{h}^{\infty} w_{\xi}\left(x_1, x_2, NT_d, (N+1)T_d\right) dx_2}{F\left(h, NT_d\right) / \gamma\left(N_{a0\min}, N_{a0\max}\right)}\right) \quad (10)$$

$N_{a0\min} = \operatorname{ceil}\left(T_{a0\min} / T_d\right)$ – lower time index, $\gamma\left(N_{\mathrm{a0\,min}}, N_{\mathrm{a0\,max}}\right)$ – correction factor that takes into account the imperfect correlation properties of the WGN in the model.

In accordance with (10), the expression for the false alarm probability is:

$$\alpha = 1 - \left[2F\left(\sqrt{h^*}\right) - 1\right] \times$$
$$\times \exp\left(-\sum_{N=N_{a0\min}}^{N_{a0\max}-1} \frac{\int\limits_{-\infty}^{h^*} dx_1 \int\limits_{h^*}^{\infty} w_{\xi_N}\left(x_1, x_2, 0, N\right) dx_2}{\left[2F\left(\sqrt{h^*}\right) - 1\right] \; / \gamma\left(N_{a0\min}, N_{a0\max}\right)}\right) \quad (11)$$

where the two-dimensional power density of the square of the Gaussian random process

$$w_{\xi_N}\left(x_1, x_2, q, N\right) = \frac{1}{8\pi\sigma^2 \sqrt{x_1 x_2 \left(1 - R_N^2\right)}} \times$$
$$\times \exp\left[-\frac{x_1 + x_2}{2\sigma^2\left(1 - R_N^2\right)} - \frac{q^2}{\sigma^2\left(1 + R_N\right)}\right] \times$$
$$\times \left\{ \exp\left[\frac{R_N \sqrt{x_1 x_2}}{\sigma^2\left(1 - R_N^2\right)} + \frac{\left(\sqrt{x_1} + \sqrt{x_2}\right)q}{\sigma^2\left(1 + R_N\right)}\right] + \right.$$
$$+ \exp\left[-\frac{R_N \sqrt{x_1 x_2}}{\sigma^2\left(1 - R_N^2\right)} - \frac{\left(\sqrt{x_1} - \sqrt{x_2}\right)q}{\sigma^2\left(1 + R_N\right)}\right] + \quad (12)$$
$$+ \exp\left[\frac{R_N \sqrt{x_1 x_2}}{\sigma^2\left(1 - R_N^2\right)} - \frac{\left(\sqrt{x_1} + \sqrt{x_2}\right)q}{\sigma^2\left(1 + R_N\right)}\right] +$$
$$\left. + \exp\left[-\frac{R_N \sqrt{x_1 x_2}}{\sigma^2\left(1 - R_N^2\right)} + \frac{\left(\sqrt{x_1} - \sqrt{x_2}\right)q}{\sigma^2\left(1 + R_N\right)}\right] \right\}$$

in which the correlation coefficient between N-th and N+1-th discrete counts of the Gaussian random process that forms the process $\xi(t)$ is equal to

$$R_N = \sqrt{\frac{N}{N+1}} \quad (13)$$

and for the same power $a^2 = \mathrm{const}$ on any k-th harmonic, $\forall k = 1, 2, .., K$, is equal to:

$$q^2 = \frac{a^2 T_{a0}}{N_0} \quad (14)$$

3. Modelling the expression for the probability of a false alarm

In Fig. 3, the black triangles represent the results of the false alarm modelling for $T_{a0\min} = 10T_d$, $T_{a0\max} = 15T_d$ and $\gamma\left(N_{a0\min}, N_{a0\max}\right) = 0.55$. The solid lines represent the calculations according to expression (11), in which the correlation coefficients R_N of the probability densities (12) are calculated according to (13).

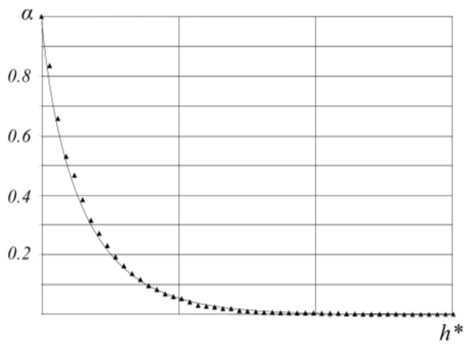

Fig. 3. Dependence of the probability of false alarm on the reduced detection threshold of the STMEI receiver

The coefficient $\gamma\left(N_{a0\min}, N_{a0\max}\right)$ is chosen in such a way that the results of theory and practice coincide as much as possible. However, the problem of justifying the coefficient remains open and must be solved in the course of developing appropriate methods based on the presented methodology.

As we can see, the results of calculations according to (11) are equally accurately confirmed by the results of modelling, regardless of T_d, including when $T_d \to 0$, at which:

$$\lim_{T_d \to 0} \frac{1}{T_d} \int\limits_{-\infty}^{h} dx_1 \int\limits_{h}^{\infty} w_{\xi}\left(x_1, x_2, t - \frac{T_d}{2}, t + \frac{T_d}{2}\right) dx_2$$
$$= \mu\left(h, t\right) = \int\limits_{0}^{\infty} y w_2\left(h, y, t\right) dy \quad (15)$$

The validity of expression (15) is easy to prove. To do this, we will use a general approach to find the joint distribution of the process and its derivative at identical moments of time t of a nonstationary process $w_2\left(h, y, t\right)$ through the two-dimensional probability density of the process distribution $w_{\xi}\left(x_1, x_2, t_1, t_2\right)$:

$$\lim_{T_d \to 0} \frac{1}{T_d} \int\limits_{-\infty}^{h} dx_1 \int\limits_{h}^{\infty} w_{\xi}\left(x_1, x_2, t - \frac{T_d}{2}, t + \frac{T_d}{2}\right) dx_2 =$$
$$= \lim_{T_d \to 0} \frac{1}{T_d^2} \int\limits_{-\infty}^{h} dx_1 \int\limits_{h}^{\infty} w_2\left(\frac{x_2 + x_1}{2}, \frac{x_2 - x_1}{T_d}, t\right) dx_2 \quad (16)$$

Replacing the variable in (16) $x_2 = x_1 + yT_d$, we proceed to the expression:

$$\lim_{T_d \to 0} \frac{1}{T_d^2} \int\limits_{-\infty}^{h} dx_1 \int\limits_{h}^{\infty} w_2\left(\frac{x_2 + x_1}{2}, \frac{x_2 - x_1}{T_d}, t\right) dx_2 =$$
$$= \lim_{T_d \to 0} \frac{1}{T_d} \int\limits_{-\infty}^{h} dx_1 \int\limits_{\frac{h - x_1}{T_d}}^{\infty} w_2\left(x_1, y, t\right) dy \quad (17)$$

and replacing in (17) $z = \left(h - x_1\right) / T_d$, we come to the double integral:

$$\lim_{T_d \to 0} \frac{1}{T_d} \int_{-\infty}^{h} dx_1 \int_{\frac{h-x_1}{T_d}}^{\infty} w_2(x_1, y, t) dy = \int_0^{\infty} dz \int_z^{\infty} w_2(h, y, t) dy \quad (18)$$

which is taken by integration by parts:

$$\int_0^{\infty} dz \int_z^{\infty} w_2(h, y, t) dy = \int_0^{\infty} z w_2(h, z, t) dz$$

and proves the validity of (15).

4. Conclusions

1. The expressions for the quality of detection of information leakage signals from monitor screens by a specialised technical means of enemy intelligence confirmed by modelling are calculated for computer systems with a finite discretisation period T_d .
2. As the computer systems of specialised technical means of enemy intelligence approach super-powerful ($T_d \to 0$), the calculated expressions for the quality indicators of signal detection approach the potential ones found in [2].
3. If the signal of side radiation from the monitor screens on liquid crystal structures is detected with potential quality indicators, any information on the monitor screen will be guaranteed to be detected by a specialised technical means of enemy intelligence with better indicators.

References

[1] Adler R. J.: Random field and their geometry. Springer, New York 2003.
[2] Adler R. J.: Random field and geometry. Springer, New York 2007.
[3] Behl D., Handa S., Arora A.: A bug Mining tool to identify and analyze security bugs using Naive Bayes and TF-IDF. International Conference on Reliability Optimization and Information Technology (ICROIT), 2014, 294–299 [http://doi.org/10.1109/ICROIT.2014.6798341].
[4] Chmielowski L., Kucharzak M.: Impact of Software Bug Report Preprocessing and Vectorization on Bug Assignment Accuracy. Choraś M., et al. (ed.): Progress in Image Processing, Pattern Recognition and Communication Systems. Springer International Publishing, Cham 2022, 153–162 [http://doi.org/10.1007/978-3-030-81523-3_15].
[5] Gnedenko B. V.: Sur la distribution limite du terme maximum d'une serie aleatore. Annals of Mathematics 44(3), 1943, 423–453.
[6] Leadbetter V. R., Lindgren G., Rootzen H.: Extreme and Related Properties of Random Sequences and Processes. Springer, New York 1983.
[7] Leadbetter V. R.: Extreme value theory for continuous parameter stationary processes. Technical rept. ADA083802, 1980-03-01.
[8] Marple S. L.: Digital spectral analysis: with application. Prentice Hall, New Jersey 1987.
[9] Yevgrafov D. V., Yaremchuk Y. Y.: Asymptotically optimal algorithm for processing side radiation signals from monitor screens on liquid crystal structures. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska – IAPGOS 13(4), 2023, 99–102 [https://doi.org/10.35784/iapgos.5586].
[10] Yevgrafov D. V., Yaremchuk Y. Y.: Quality indicators of detection of side radiation signals from monitor screens by a specialized technical means of enemy intelligence. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska – IAPGOS 14(1), 2024, 21–26 [https://doi.org/10.35784/iapgos.5610].

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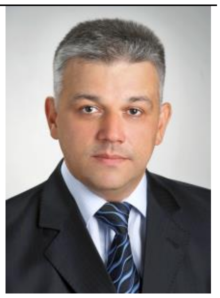

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