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ALGORITHMS AND MODELS FOR SYNTHESIS OF ELEMENTS OF DIGITAL INFORMATION SYSTEMS

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Abstract: *The development of algorithms for noise-tolerant and high-speed measurement systems involves an integrated approach that encompasses methods of data processing and transmission, as well as mechanisms for rapid response to changes. This paper presents the key principles and techniques used in such technologies. The information systems are thoroughly analyzed, including the use of signal processing techniques and their identification, filtering using various statistical techniques to determine signal parameters and the development of algorithms to analyze and classify signals. Critical aspects of the system such as performance, reliability, security and scalability are also evaluated. The paper discusses information system structures and presents performance analyses that evaluate the effectiveness of digital information system components.*
Keywords: *Information systems, white noise, error, Kotelnikov's theory, optimal filter, signal parameters, correlation method.*

Annotatsiya: *Shovqinga bardoshli va yuqori tezlikga ega o'lchash tizimlari uchun algoritmlarni ishlab chiqish ma'lumotlarni qayta ishlash va uzatish usullari, shuningdek, o'zgarishlarga tezkor javob berish mexanizmlarini qamrab oladigan kompleks yondashuvni o'z ichiga oladi. Ushbu maqolada shu kabi texnologiyalarda qo'llaniladigan asosiy tamoyil va uslubiyatlar keltirilgan. Axborot tizimlari izchil tahlil qilingan, jumladan, signallarga ishlov berish va ularni identifikatsiyalash usullaridan, signal parametrlarini aniqlash uchun turli statistik usullar yordamida filtrlash va signallarni tahlil qilish va tasniflash algoritmlarini ishlab chiqishdan foydalangan holda amalga oshirilgan. Shuningdek unumdorlik, ishonchlilik, xavfsizlik va masshtablilik kabi tizimning muhim jihatlari ham baholangan. Maqolada axborot tizimlarining strukturalari muhokama qilinib raqamli axborot tizimlarining tarkibiy qismlarining samaradorligini baholash imkonini beradigan ishchi xarakterstikalarningi tahlili taqdim etilgan.*
Tayanch so'zlar: *Axborot tizimlari, oq shovqin, xatolik, Kotelnikov nazariyasi, optimal filtr, signal parametrlari, korrelyatsiya usuli.*

Аннотация: *Разработка алгоритмов для помехоустойчивых и высокоскоростных измерительных систем включает комплексный подход, который охватывает методы обработки и передачи данных, а также механизмы быстрого ответа на изменения. В работе представлены ключевые принципы и методики, применяемые в таких технологиях. Тщательной анализируется информационные систем, включая методы обработки сигналов и их идентификацию, фильтрацию с использованием различных статистических методов для определения параметров сигнала и с разработкой алгоритмов для анализа и классификации сигналов. Также проводится оценка важнейших аспектов системы, таких как производительность, надежность, безопасность и масштабируемость. Обсуждаются структуры информационных систем и представлены результата анализы рабочих характеристик, которые позволяют оценить эффективность компонентов цифровых информационных систем.*
Ключевые слова: *Информационные системы, белый шум, ошибка, теория Котельникова, оптимальный фильтр, параметры сигнала, корреляционный метод.*

Introduction

To create noise-tolerant fast measurement systems for information processing, information transmission or decision making, it is necessary to determine the best course of action from a variety of available options. Various factors such as speed, accuracy, power consumption, hardware resources, and others must be considered when developing algorithms for information operational data and signal processing. The use of proper algorithms plays a key role in ensuring the reliability, efficiency and security of information systems.

In digital information systems, signals are usually represented as binary data, where logic level “0” corresponds to no signal or low voltage level, and logic level "1" corresponds to the presence of a signal or high voltage level. These two levels form the basis for the transmission, processing and storage of information in the system. The algorithms used in such systems can be defined by different states and transitions between them. It is important to note that these algorithms can be implemented in the form of software, hardware or a combination of both, depending on the specific requirements and characteristics of the system [1,2]. For this purpose, it is necessary to solve two main tasks - the task of synthesis and analysis of the created information systems. At the synthesis stage, the key characteristics and parameters of the system are identified, which should be taken into account when developing the algorithm of functioning. Quality criteria may vary depending on the specific area of application of the system and include such factors as speed of data processing, accuracy of results, efficiency of resource utilization and others.

Information systems analysis evaluates various aspects of an information system, including its performance, reliability, security, scalability, and other characteristics. Performance calculations determine how efficiently and effectively a system will perform its functions under specific operating conditions.

Signals, which are the carriers of information, and the interference that acts on them during transmission, are also random processes. For example, interference can be caused by various factors such as electromagnetic influences, atmospheric conditions or internal noise in electronic devices. One of the options for finding algorithms for information processing under conditions of random interference is static synthesis using probabilistic models.

The use of this method consists in applying various methods of statistics, probabilistic analysis and machine learning. It involves the development of statistical models, estimation of parameters of these models on the basis of available data and development of data processing algorithms that take into account the statistical characteristics of signals and interference. The signal detection process usually starts with pre-processing of the input data, such as filtering or signal amplification. Various statistical methods and algorithms are then applied to analyze and classify the signal. This may include determining the statistical parameters of the signal, such as amplitude, frequency, duration, and comparison with reference samples or signal models [3-5].

Methods

When recognizing signals, it is important to consider the possibility of errors. Errors can be of different types and are classified as 1st and 2nd type errors. An error of the 1st kind occurs when the system incorrectly detects the presence of a signal where it is not actually present. This means that the system is falsely triggered, i.e. interference or background noise is perceived as the presence of a signal. In terms of this problem, the conditional erroneous decision about the presence of signal $x_1$when taken as x_2, and is denoted as α.

A type 2 erroneous decision occurs when the system does not detect a useful signal. This means that the system fails to trigger, it does not recognize the presence of the signal although it is present. In terms of this problem, the conditional probabilities of erroneous decisions about the presence of signal x_2 when $x_1$is accepted are denoted as β.

Note that the probabilities of making an incorrect decision are expressed as $\mathrm{P}_0 = \mathrm{q}\alpha + \mathrm{p}\beta$, where q is the a priori probability of absence and p is the a priori probability of the presence of a useful signal. Conventionally, graphical representations of the density distribution define the characteristic of incoming signals of state a_1, or states a_2 (Fig. 1).

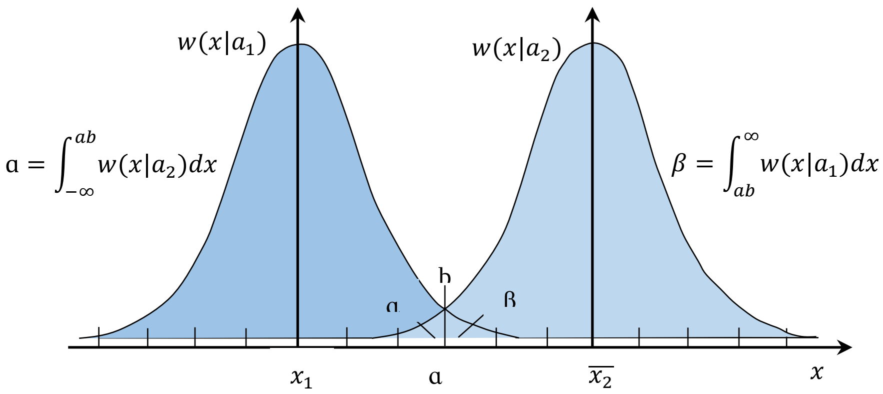

Fig. 1. ***Graphical representations of the conditional probability density distribution in a symmetric channel.***

Given in a symmetric channel α=β. Also, suppose the source produces only two equal signals x_1 and x_2, expressed by the event $[P(x_1) + P(x_2) = 1]$, then at the output of the receiving element four events are possible, which make up the following complete group: $P(x_1') + \alpha + P(x_2') + \beta = 1$. Judging by the graphical representation, (Fig. 1), the boundary for distinguishing the features of the plots ab passes through the area of intersection of the density plots. When the conditions $w(x \mid a_1) = w(x \mid a_2)$ are satisfied, the criterion of maximum graph matching α=β is fulfilled. However, the probability of taken erroneous algorithmic decisions depends besides the variety of signals given, and at the same time depends on the a priori information probability states, which correspond to states a_i $(u = 1{,}2)$ of the object. The graphs of the corresponding group of events $P(x_i)w(x \mid a_i)$ are presented in Fig. 2.

The content of the current reference can be presented as follows: when the signal y_i arrives at the receiver input, it is processed, as a result of which a decision is made about the presence or absence of a signal. If the count value y_i exceeds the threshold value set for this criterion of signal detection, then it is considered that the signal is detected, otherwise - no signal [6-9].

The realizable effective value of the input signal is defined as the sum of two components: the useful informative signal and the accompanying interference

$$y_i = s_i + n_i. \qquad (1)$$

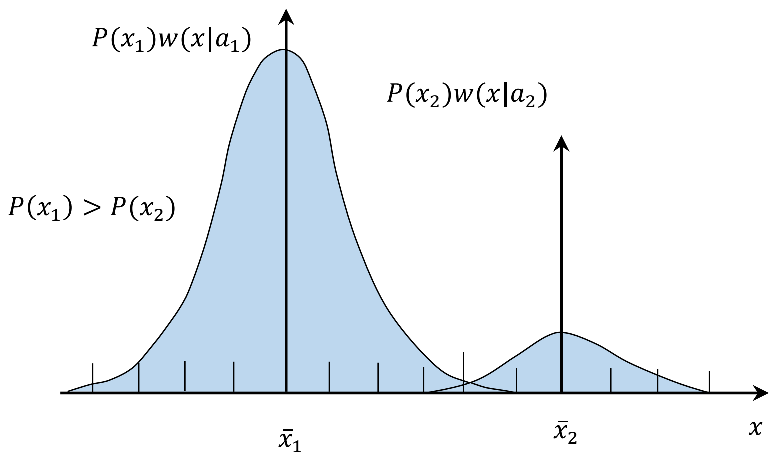

Fig. 2. ***Arrangement of the system of voltage vectors of the AVI on the phase line.***

If there is no useful informative signal in the processes: $s_i = 0$ и $n_i \neq 0$.Then the expression takes place:

$$P(y/0) = P(y_i/0) = P(n_i) = w(n_i)dx_i = w(y_i)dy_i \qquad (2)$$

where $w(n_i)$ are the probabilities of the interference density.

The expected probability of actually using a signal with interference, both in transmission and as reception $P(y/s)$ uniquely coincides with the probability of repetition of random variables ($y_i - s_i$), which is defined as n_i. Where

$$P\left(\frac{y}{s}\right) = P\left(\frac{y_i}{s_i}\right) = P(y_i - s_i) = w_i(y_i, s_i)dy_i,$$

$$\Lambda = P\left(\frac{y}{s}\right) = P\left(\frac{y}{0}\right) = \frac{w_i(y_i,s_i)}{w(y_i)}. \quad (3)$$

We can take the accompanying noise as a stationary normal random process with zero mean component and equal variance σ^2.

$$w_1 = w(y_i, s_i) = \exp\{-(y_i - s_i)^2/(2\sigma^2)\};$$
$$w = w(y_i) = \exp\{-(y_i)^2/(2\sigma^2)\}/\sqrt{2\pi\sigma^2} \quad (4)$$

From the last expression (4) we can conclude that, when the value of s_i and σ^2 are known, there is a one-to-one reciprocal relation between the corresponding samples y_i and Λ. For each real value of y_i belongs to a fully corresponding value of Λ. Having in mind when $\Lambda = \Lambda_\text{p}$ it is sufficient to compare the value of y_i with a small distinctive threshold:

$$y_\text{p} = (\sigma^2 \ln \Lambda_\text{п} + 0{,}5 s_i^2)/s_i. \quad (5)$$

In cases where $y_i > y_\text{p}$ then a positive decision "yes" is made and in other cases: $y_i < y_\text{p}$ a negative decision “no” is made.

Discussion

Thus, the one-time reference method is a simple but important tool for signal processing and making appropriate decisions based on real-time observations.

In dynamic information processing, the signal y(t) is continuously compared with a threshold value y_p. If the signal exceeds the threshold, the signal is said to be detected. This approach helps to reduce the probability of missing a signal and improve the detection reliability [10-15].

Since the probability of the signal exceeding the threshold in the solver is determined by the

$$P_{\text{p.}} = P[(y_i > y_\pi)/0] = \int_{y_\pi}^{\infty} w(y)dy, \quad (6)$$

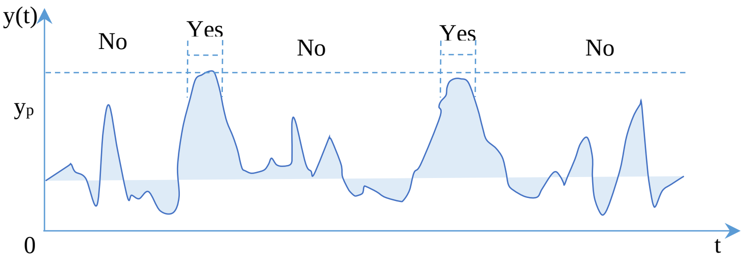

Fig. 3. ***Schedule of the information processing process.***

Probabilities of missing information:

$$P_{\text{prp}} = P[(y_i < y_\text{п})/s] = \int_{-\infty}^{y_n} w_1(y)dy, \quad (7)$$

Relative for white noise if Δτ→0. Then

$$\Lambda = \prod_{=1}^{N} w_i(y_i, s_i)/\prod_{i=1}^{N} y_i \quad (8)$$

And in the relation for random processes with variance σ^2 the matching parameters can be written:

$$\Lambda = \exp\{\textstyle\sum_{i=1}^{N} [-(y_i - s_i)^2/2\sigma^2]\}/\exp\{\sum_{i=1}^{N} (-(y_i^2/2\sigma^2)\} \quad (9)$$

Transforming expressions (9) we have

$$\ln \Lambda = (\textstyle\sum_{i=1}^{N} s_i y_i - 0{,}5\sum_{i=1}^{N} s_i^2)/\sigma^2 \quad (10)$$

The wording of the data processing can be written in the following way

$$\left(a_y\right)_N = \textstyle\sum_{i=1}^{N} s_i y_i = \sigma^2 \ln \Lambda + 0{,}5\sum_{i=1}^{N} s_i^2, \quad (11)$$

As the processing proceeds, determining ($\sum_{i=1}^{N} s_i y_i$) and comparing the sum found with the threshold sum

$$(a_y)_N^{\Pi} = \sigma^2 \ln \Lambda_{\Pi} + 0{,}5 \sum_{i=1}^{N} s_i^2 \quad (12)$$

which we calculate from expression (10) when $\Lambda = \Lambda_p$

In cases when $(a_y)_N > (a_y)_N^n$ then the positive statement "yes" is accepted. When sampling takes place in the interval $[0, t]$, and the reference data is defined through the moments Δτ→0, then the sums defined according to expression (12) are equal to the integral, and $\sigma^2 \Delta\tau$ is defined as the power spectral density. As a result, we obtain:

$$\int_0^{t_0} s(t)y(t)dt = \ln \Lambda + 0{,}5 \int_0^{t_0} s^2(t)dt. \quad (13)$$

Using the correlation method, the receiver collects information over a period of time, processes this data and searches for correlations between them. If a signal is present, correlation analysis identifies the signal as some distinctive sequence from background noise and interference. [16-20].

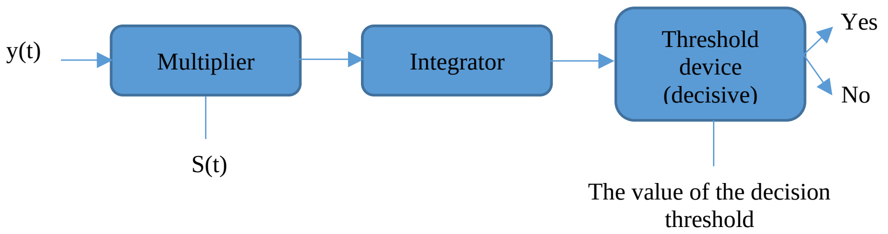

Fig. 4. ***Functional building blocks of the device for signal processing by correlation method.***

Expressions (13) defines the sequence on decision making and allows, on the basis of analysing the similarity between the desired and received signal, integrating them over a certain time interval, to make a conclusion about the presence or absence of a signal, based on a given threshold value.

Let's look at the principles that form the basis for creating ideal detectors for coherent reception. Let us imagine that a coherent receiver for the expression of input signals 1 and 0 correspond to functions A(t) and B(t) with the same validity time tc. In this case, the input signal x(t) is a combination of signal and thermal or flexural noise Based on Kotelnikov's theory, to reduce the probability of errors in the performance of data transmission, the receiver should select signal A if the specific statement is satisfied: I(A) < I(B). Otherwise, signal B should be selected. However:

$$I(B) = \int_0^{t_c} [x(t) - B(t)]^2 dt; I(A) = \int_0^{t_c} [x(t) - A(t)]^2 dt \quad (14)$$

where t_c- denotes the duration of the binary signal. Using expression (14), we can structurally represent the ideal receiver according to the Kotelnikov theory (Fig.5).

The Kotelnikov receiver design includes reference signal generators that accurately reproduce signals A and B from the transmitters; subtractors; a squaring device; an integrator I; and a solver. To create the reference signals, the receiver needs to know all the characteristics of the transmitted signals A and B. The receiver is divided into two parts, each of which calculates the standard deviation of the received signal x(t) from a known reference: in the first part for signal A(t), in the second part for signal B(t). The choice between signals A and B is made on the basis of in which branch the difference appears to be smaller [21-27].

Optimal active and passive pause receivers use different energy efficiency strategies for signals A and B. We denote the energy of signals A and B, assuming a 1 ohm resistor, as E_I and E_B respectively:

$$E_A = P_A, t_c = \int_0^{t_c} [A(t)]^2 dt; E_B = P_B, t_c = \int_0^{t_c} [B(t)]^2 dt, \quad (15)$$

where P_A and P_B represent the average specific power of signals A and B developed on a unit resistor.

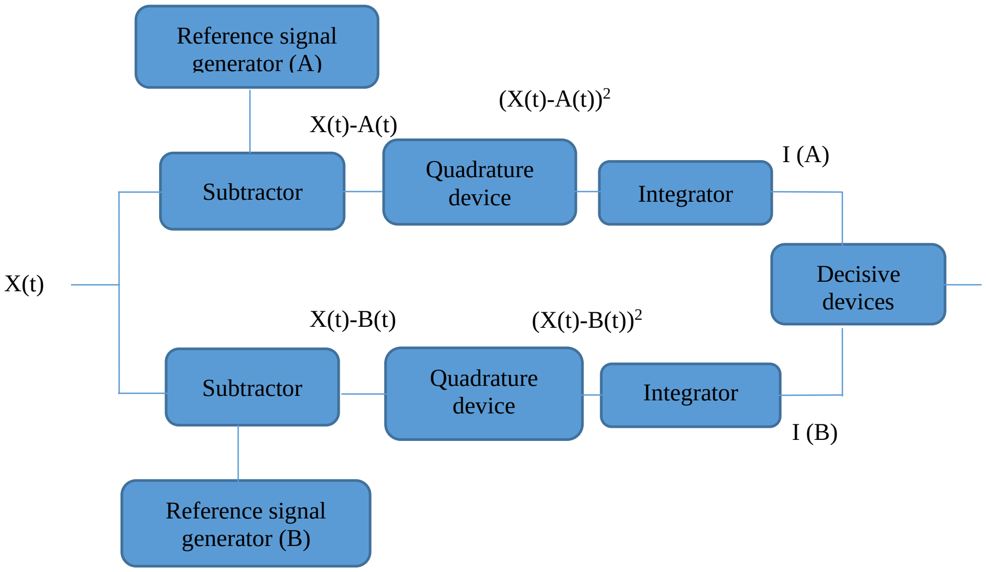

Fig. 5. ***Structure-block representation of the receiver by Kotelnikov theory.***

A signal with passive pause is characterised by the fact that it is actively radiated only when one of the symbols (e.g. symbol "1") is transmitted, while the transmission of the other symbol (e.g. "0") corresponds to a period without radiation. In such a case:

$$A(t) \neq 0,\ B(t) = 0, E_A = E, E_B = 0 \tag{16}$$

The use of pauses in the transmission of certain signals helps to reduce the overall power consumption of the system. Using expressions (15) and (16) in formula (14), we can describe the algorithm of the optimal receiver for signals with passive pause as follows:

$$\int_0^{t_c} x(t)A(t)dt \geq \frac{E}{2 \text{ - signal received A}} \tag{17}$$

$$\int_0^{t_c} x(t)A(t)dt \leq \frac{E}{2 \text{ - signal received B.}} \tag{18}$$

The left part of these expressions is the correlation integral, which evaluates the mutual correlation between the received signal x(t) and the reference signal A(t). By rule (18), the receiver calculates the value of the correlation integral and compares it with a given threshold. Thus, the optimal receiver for signals with passive pause is a correlation receiver consisting of a correlator and a solver.

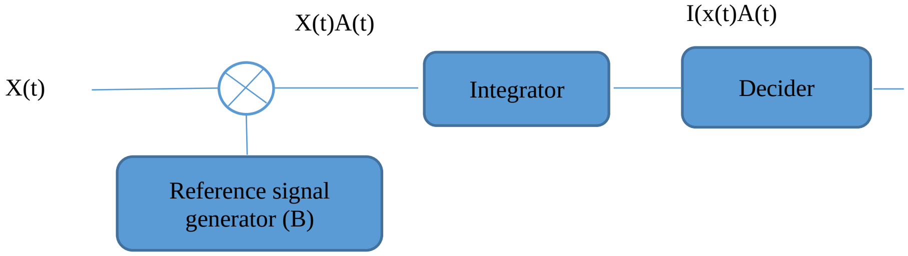

Fig. 6. ***Block diagram of an optimal correlation receiver with a passive pause.***

A correlation receiver includes a multiplier, a decision unit, an integrator, and a sampling device that is not shown in the schematic but operates at times corresponding to the durations of the signals $(t_k = kt_c, k = 1,2, \dots)$ This receiver is also known as a coherent receiver with passive pause. If we use a linear filter tuned to the signal A(t) to calculate the correlation integral, we obtain a receiver with an optimal filter I(x(t)A(t)).

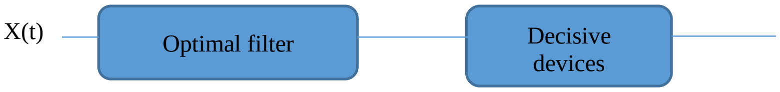

Fig. 7. ***Structural diagram with optimal filter of the receiver with passive pause.***

A signal with an active pause means that emission occurs when either character (0 or 1) is transmitted, with the signal retaining a binary structure to distinguish between the two values. Usually such signals have the same energy values: $E_A = E_B = E$. Modifying formula (15), we obtain the following equation:

$$2\int_0^{t_c} x(t)A(t)dt - \int_0^{t_c} [A(t)]^2 dt > 2\int_0^{t_c} x(t)B(t)dt - \int_0^{t_c} x(t)B(t)dt - \int_0^{t_c} [B(t)]^2 dt. \quad (19)$$

Given $\int_0^{t_c} [A(t)]^2 dt = \int_0^{t_c} [B(t)]^2 dt$, two possible solution equations can be derived.

First variant: $\int_0^{t_c} x(t)A(t)dt - \int_0^{t_c} x(t)B(t)dt > 0$- then signal A is received, $\int_0^{t_c} x(t)A(t)dt - \int_0^{t_c} x(t)B(t)dt < 0$ - then the signal " B is received.

The second variant $\int_0^{t_c} x(t)\Delta A(t)dt > 0$- then the signal A is received, $\int_0^{t_c} x(t)\Delta A(t)dt < 0$ - then signal B is received, where $\Delta A(t) = A(t) - B(t)$.

These formulas provide various scenarios for the operation of an optimal receiver with active pause. In the process of developing algorithms for processing information data and signals, it is crucial to consider many parameters including processing speed, accuracy, energy efficiency, hardware requirements, and other critical aspects.

Conclusion

Engineers and researchers need to determine the most effective processing and implementation methods, taking all these aspects into account. Information system structures summarize the description of components, their relationships and interactions, and the architectural approaches chosen in designing the system. These structures provide a comprehensive understanding of the system and contribute to a deep understanding of its design and operating principles.

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