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SATELLITE SIGNAL DETECTION METHOD BASED ON MODIFICATION COMPRESSION OPERATOR

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Abstract. *The modification of compression operator on the basis of polynomial approximation with analytic connection has been proposed. The approximation of two discrete sequences between determinated bases with analytical relation has been reviewed. The characteristics of meander signal have been built with a help of classic and proposed methods.*

Keywords: signal; polynomial approximation; analytical relation; compression operator.

Introduction

The issue of signal detection plays a significant role in the modern radiolocation. One of the existing issues is an increase of navigation signal detection probability. And one of the existing problems on its path is a multipath signal expansion.

Reasons of occurrence and attempts to decrease the influence of noises with different origination on the radio and satellite navigation system signals are presented in sources [1; 2]. The authors of these sources propose methods of filtration improvement of the detected signal and noises, but they do not provide improvement of signal detection. Unlike those methods the proposed one allows to increase signal detection probability in navigation and radiolocation.

Task statement

First of all unknown fluctuations of the signals from ideal harmonic model result in significant decrease of characteristics of these signals detection. That's why there is need in the method which will stand against such fluctuations. There is also an important task to solve scientific and technical problem of development of methods and means of efficiency increase of the initial processing algorithms of radiolocation information under conditions of uncertainty in terms of signal and noises distribution, that has an important practical meaning.

Solution of the stated task

Splines in some cases have good approximation properties that provide minimum probable margin for solution of practical and technical tasks of results determination processing. Also it should be mentioned that splines application considerably decrease calculations number. To renew discrete metrical information s approximating usually polynomial spline functions are used (or splines), much contribution of which was made by J. Alberg, E. Nilson, J. Walsh, M.P. Korneychuk, B.G. Marchenko, V.P. Denisyuk, M.O. Shutko, etc. [3; 4]. The above mentioned author developed splines for approximation of sole unipolar or n-measured sequences. This article unlike above mentioned includes development spline-approximation of 2 noisy sequences between determined bases of which there is an analytical relation.

The tasks of numerical data processing that include random values often require the evaluation of meander sequence trends among which there is some analytical relation.

In real situation the amplitude, wave and phase of the received meander signal have natural noises that depend on transmitter stability, satellite model, its distance, natural conditions, etc. So let's consider a general model of meander signal

$$s\left(t-t_0\right)=Ad(t-t_0)\cos\left[\omega_0\left(t-t_0\right)+\varphi\left(t\right)\right]+\gamma(t), \quad (1)$$

where A is signal amplitude, $\omega_0=2\pi f_0$ is circular carrier wave, $\varphi\left(t\right)$ is signal phase, t_0 is reference point, $d\left(t\right)$ is meander pseudo-random sequence of range-measurement code, $\gamma(t)$ is independent indicators of normal noise with zero medium and one-value of mean-square deviation.

Meander pseudo-random sequence of range-measurement code $d\left(t\right)$ (for informational signal) is a result of multiplication of normally four sequences: pseudo-random sequence of range-measurement code itself, additional meander fluctuation, navigation messages and messages of synchrocode to provide clocking synchronization while operating. Then for conciseness let's consider that, meander pseudo-random sequence $d\left(t\right)$ is conditioned by pseudo-random sequence of range-measurement code and meander fluctuation.

Typical meander pseudo-random sequence of range-measurement code $d(t)$ can be cast in the form of

$$d(t-t_0)=g(t-t_0)r(t-t_0),$$

where $g(t)$ is pseudo-random sequence of range-measurement code, which is also typical for traditional satellite radio-navigation system; $r(t)$ is meander fluctuation, that reflects the specific features of new class signals of satellite radio-navigation system.

Consequently meander pseudo-random sequence $d(t)$ is formed by multiplication of mutually synchronized bit sequences $g(t)$ and $r(t)$, and each of them consists of single video-impulses of a certain length that interchange and change their polarity according to certain laws depending on code index that can be equal to +1 or -1.

Meander fluctuation $r(t)$ is calculated with a help of [5; 6]

$$r(t)=\mathrm{sign}[\sin\omega_M t],$$

where function "signum" z is equal to

$$\mathrm{sign}\,z=\begin{cases}1, & z>0;\\ 0, & z=0;\\ -1, & z<0.\end{cases}$$

$\omega_M=2\pi f_M$ is circular meander fluctuation wave, $f_M=1/T_M$ is meander fluctuation wave, $T_M=2\tau_M$ is period of meander fluctuation, τ_M is meander fluctuation impulse length.

The expression of pseudo-random sequence of range-measurement code $g(t)$, that describes its one period has the following form [3]

$$g(t-t_0)=\sum_{k=0}^{L-1}\nu_k \mathrm{rect}_c[t-k\tau_c-t_0],$$

where τ_c is symbol length (element) of pseudo-random sequence; L is number of symbols in pseudo-random sequence period; t_0 is initial condition; $k=0,1,2,\ldots,(L-1)$. Function $\mathrm{rect}_c[\cdot]$ is an impulse of a single amplitude with length τ_c

$$\mathrm{rect}_c[t-k\tau_c]=\begin{cases}1 & \text{if } k\tau_c\le t<(k+1)\tau_c;\\ 0 & \text{if } k\tau_c>t\ge(k+1)\tau_c.\end{cases}$$

Code indexes ν_k that form pseudo-random sequence at each interval τ_c take the value +1 or -1 according to the law of symbols interchange at its period. A period length of pseudo-random sequence is equal to $T_L=L\tau_c$.

While developing noise-proof method of meander signal detection against the background of wide range of natural noises and multipath effect, a physical principle is applied – if there are no noises, the signal is a meander.

I.e. time sequence of the process (1) is presented by

$$g(t)=\{g(0),\ g(1),\ldots,\ g(N-1)\}.$$

And then they are processed by discrete compression.

Let's review observations of meander signal without any noises

$$s(t-t_0)=Ad(t-t_0)\cos[\omega_0(t-t_0)+\varphi(t)]. \quad (2)$$

We can note that after multiplication of vector-column, consisting of reference points $g(t)$, and code sequence of Galileo, the result will be presented by reference points of integration function $y(t)$ with constant amplitude. The value of this amplitude depends on amplitude A, but it's important that

$$y(t)=\mathrm{const1},\qquad t=\overline{0,N-1}.$$

Its' obvious that accumulation of such reference points is in accordance with linear laws. After gradual increase of reference points $y(t)$ we will receive reference points of initial function $h(t)$, the value in point $t=N-1$ of which is equal to amplitude of signal compression in its maximum. Therefore the following correlations are constant [4]

$$c(t)=\frac{h(t)}{y(t)}=t+1,\quad t=\overline{0,N-1}, \qquad (3)$$

Then for principal model of meander signal (1) let's build a method of polynomial sequence smoothing $h(t)$ and $y(t)$ applying relation conditions (3). We will note that although reference points of normal noise $\gamma(t)$ are independent, noise components of sequence $h(t)$ will be correlated.

Initially let's build polynomial evaluation for two sequences without taking into account correlation features of noise components $h(t)$, and then we will consider them with a help of generalized least square method.

Mutual correlation between reference points $y(t)$ and $h(t)$ quickly decrease to zero value. In real situation correlation features of the useful random signal are impossible to take into account due to absence of the necessary priory information, while correlation matrix for background noises can be always determined numerically.

Let's build the following functionality:

$$\Phi_R = \sum_{t=0}^{N-1}\{h(t) - S_h(t)\}^2 + \sum_{t=0}^{N-1}\{y(t) - S_y(t)\}^2 + \lambda\sum_{t=0}^{N-1}\{S_h(t)] - (t+1)S_y(t)\}^2, \quad (4)$$

where $S_h(t) = ZA_h$ and $S_y(t) = PA_y$ are cubic polynomials, which approximate reference points of initial $h(t)$ and integration $y(t)$ functions; Z, P are planning matrices (in general they can be not similar due to different location of indexes) for polynomials S_h, S_y; $A_h = \{a_{hl}\}_{l=1}^{4}$, $A_y = \{a_{yl}\}_{l=1}^{4}$ are vectors of parameters to be evaluated (indexes of cubic polynomials).

Cubic polynomial in random point is calculated with a help of the following formula

$$\dot{S}(\omega) = \dot{a}_{l-1}\,{}^1x(\omega) + \dot{a}_l\,{}^2x(\omega) + \dot{a}_{l+1}\,{}^3x(\omega) + \dot{a}_{l+2}\,{}^4x(\omega),$$

where ${}^m x(\omega)$ is from functions, $m = \overline{1...4}$; $\dot{a}_l$ are values of polynomial indexes, $l = 1,2,...,4$.

Let's minimize the functionality $\Phi_R = \min$.

For that we need solution of the following system of equations:

$$\begin{cases} \dfrac{\partial \Phi_R}{\partial a_{hl}} = 0, & l = \overline{1,s}; \\ \dfrac{\partial \Phi_R}{\partial a_{yl}} = 0, & l = \overline{1,s}, \end{cases}$$

Let's write functionality Φ_R in the form of matrix

$$\Phi_R = (H - ZA_h)^T(H - ZA_h) + (Y - PA_y)^T(Y - PA_y) + \lambda(ZA_h - \tilde{\mathbf{P}}A_y)^T(ZA_h - \tilde{\mathbf{P}}A_y),$$

λ has index (in this case $\lambda = 1$), where matrix

$$\tilde{\mathbf{P}} = \begin{bmatrix} -1p_{11} & -1p_{12} & \dots & -1p_{1s} \\ -2p_{21} & -2p_{22} & \dots & -2p_{2s} \\ \vdots & \vdots & \vdots & \vdots \\ -Np_{N,1} & -Np_{N,2} & \dots & -Np_{N,s} \end{bmatrix} \quad (5)$$

Let's specify

$$R = \begin{bmatrix} H \\ Y \\ D \end{bmatrix}, \quad H = [h(0),\, h(1), ...,\, h(N-1)]^{\mathrm{T}},$$

$$Y = [y(0),\, y(1), ...,\, y(N-1)]^{\mathrm{T}}.$$

Vectors that consist of reference points of the initial and integration functions $D = [0,0,...,0]^{\mathrm{T}}$, dimensions $(N{*}1)$; $\mathbf{A} = \begin{bmatrix} \mathbf{A_h} \\ \mathbf{A_y} \end{bmatrix}$, $\mathbf{A_h} = [a_{h1}, a_{h2}, ..., a_{hs}]^{\mathrm{T}}$, $\mathbf{A_y} = [a_{y1}, a_{y2}, ..., a_{ys}]^{\mathrm{T}}$ are vectors of polynomial indexes.

Then let's specify $\mathbf{W} = \begin{bmatrix} \mathbf{Z} & \mathbf{O} \\ \mathbf{O} & \mathbf{P} \\ \mathbf{Z} & \tilde{\mathbf{P}} \end{bmatrix}$, $\mathbf{Z}, \mathbf{P}$ are matrices of polynomial planning, the columns of which are represented by functions of polynomial form ${}^m z(t),\ {}^m p(t),\ m = 1...4;$; $\mathbf{O}$ is zero matrix, dimensions $N * r$; $\tilde{\mathbf{P}}$ is matrix (5).

Matrix dimensions $\mathbf{W}$ - $(3N * 8)$.

Then the requirements of least-square method

$$(R - WA)^{\mathrm{T}}(R - WA) = \min.$$

Then classic relation

$$A = (W^{\mathrm{T}}W)^{-1}W^{\mathrm{T}}R.$$

And taking into account correlation of generalized least-square method solution:

$$\tilde{\mathbf{A}} = (W^T\tilde{\mathbf{M}}\,W)^{-1}W^T\tilde{\mathbf{M}}\,R,$$

where $\tilde{\mathbf{M}} = \begin{bmatrix} \mathbf{M^{-1}} & \mathbf{O} & \mathbf{O} \\ \mathbf{O} & \mathbf{E} & \mathbf{O} \\ \mathbf{O} & \mathbf{O} & \mathbf{E} \end{bmatrix}$, $\mathbf{M^{-1}}$ – inverse matrix to the correlation matrix of noise components $h(t)$; $\mathbf{E}$ is single matrix, dimensions ($N * N$); $\mathbf{O}$ is zero matrix, dimensions $N * N$.

Let's find $\tilde{\mathbf{S}}_{\mathbf{h}} = Z\tilde{\mathbf{A}}_{\mathbf{h}}$, $\tilde{\mathbf{S}}_{\mathbf{y}} = \mathrm{P}\tilde{\mathbf{A}}_{\mathbf{y}}$ is cubic polynomials that are built considering analytical relations (4).

These values are obtained via polynomial aligning of time sequences $h(t)$ and $y(t)$ under conditions (3) that correspond meander signal model (2). Let's outline that by aligning of useful signals (distorted by noises) sequences, we also "align" sequences of noise components in case of absence of useful information.

Results

To determine the probability of the correct signal detection and building of characteristics of detection, it's necessary to set fixed value of false alert probability, let's take the following value $F_{xm} = 10^{-3}$. That means that we programmatically pick up the value to meet requirement of availability of minimum 30 detections out of 30000. Then we calculate the limit value, i.e. the value over which the signal is available, and below which there is no signal.

Let's build the characteristics of the proposed method and classic method, obtained with a help of computer modeling (Figs. 1–4).

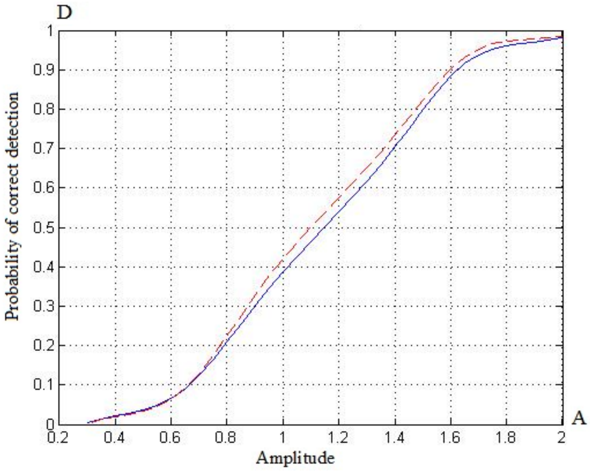

Fig. 1. Characteristics of meander two-radial signal detection based on: proposed (dashed lines) and classic (solid lines) methods

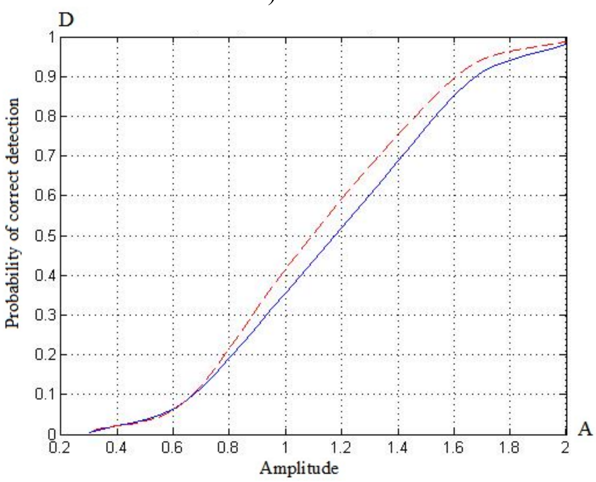

Fig. 2. Characteristics of meander three-radial signal detection based on: proposed (dashed lines) and classic (solid lines) methods

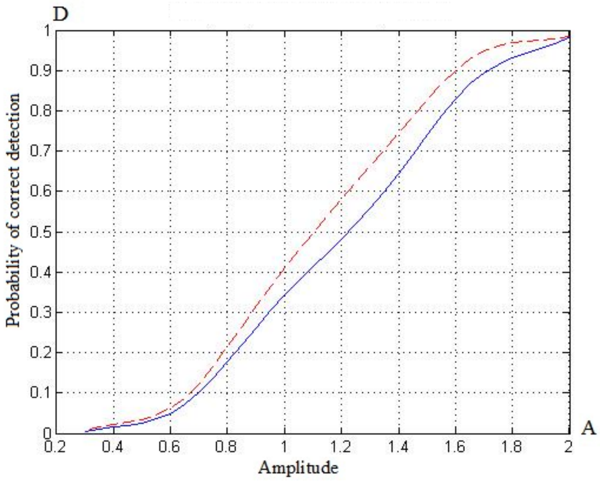

Fig. 3. Characteristics of meander four-radial signal detection based on: proposed (dashed lines) and classic (solid lines) methods

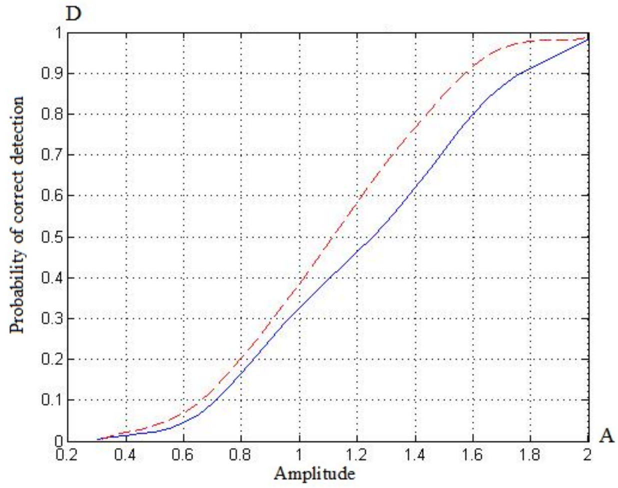

Fig. 4. Characteristics of meander five-radial signal detection based on: proposed (dashed lines) and classic (solid lines) methods

Conclusion

Thus, the developed method is competitive comparing with classic method of Galileo satellite signal detections and other satellite radio-navigation system in complex noise situation. Applying of the polynomial approximation method with analytic relations allows to increase probability of correct detection and signal/noise relations.

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А. О. Юрчук, О. О. Колганова, В. В. Конін, В. М. Шутко. Метод виявлення супутникових сигналів на основі модифікації оператора згортки

Запропоновано модифікацію оператора згортки на основі поліноміальної апроксимації з аналітичним зв'язком. Розглянута апроксимація двох дискретних послідовностей між детермінованими основами яких існує аналітичний зв'язок. Побудовані характеристики виявлення меандрового сигналу класичним та запропонованим методами.

Ключові слова: сигнал; поліноміальна апроксимація; аналітичний зв'язок; оператор згортки.

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А. А. Юрчук, Е. О. Колганова, В. В. Конин, В. Н. Шутко. Метод выявления спутниковых сигналов на основе модификации оператора свертки

Предложена модификация оператора свертки на основе полиномиальной аппроксимации с аналитической связью. Рассмотрена аппроксимация двух дискретных последовательностей между детерминированными основами которых существует аналитическая связь. Построенные характеристики выявления меандрового сигнала классическим и предложенным методами.

Ключевые слова: сигнал; полиномиальная аппроксимация; аналитическая связь; оператор свертки.

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