Yaroslav A. KULYK[1], Bogdan P. KNYSH[1], Yuryy Yu. IVANOV[1], Anatolii V. POPLAVSKYY[1], Andrzej KOTYRA[2], Nataliya DENISSOVA[3], Gulzat ZIYATBEKOVA[4]

Vinnytsya National Technical University (1), Lublin University of Technology (2),
East Kazakhstan State Technical University named after D.Serikbayev (3), Al-Farabi Kazakh National University (4)

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The enhanced method of a spectrum's window estimation

***Abstract**. In this paper is proposed the advanced method of the spectrum's window estimation, which, in opposition to currently existing methods, uses the mean multiwindow estimation of the logarithm' signal spectrum, which cause the more strict signal's spectrum estimation and increasing the efficiency of the trash-hold methods of the signals estimation. Analyzing its efficiency is provided by the means of the numerical experiments and by the implementation of modeling the nets can program.*

Streszczenie.** W artykule przedstawiono zaawansowaną metodę estymacji okna widmowego, która wykorzystuje średnią wielookienkową estymację widma sygnału logarytmicznego. Analizowanie efektywności metody odbywa się za pomocą eksperymentów numerycznych oraz poprzez wdrożenie modelowania sieci z możliwością programowania. (**Ulepszona metoda estymacji okna widmowego).

Keywords: Signal processing, window transformation, multiwindow spectrum estimation.
Słowa kluczowe: Przetwarzanie sygnałów, transformata okienkowa, wielookienkowa estymacja widma

Introduction

Constunt increasing computer technologies' and the systems' implementation takes place in the geometrical progression's order, and the key feature of the computer's system development is the creation of the highly efficient and highly reliable methods of a data transmitting and receiving. Among all computer's networks the important place take the networks, that can provide the good work's results in the environment, that has a high level of the noises. Those are the industrial and the radio networks. In the industry the authenticity of the transmitted information is more important, than the speed of transmitting and very often there is the necessity to provide information transmitting in any conditions of the environment. In the Wi-Fi networks, when the error probability is 0.1, the loss of the transmitted information is 40%, and when the level of the noises is higher, the transmitting is impossible at all [1]. According to the radio networks standards [2], especially the Wi-Fi, WiMAX networks, the level of signal/noise should be more than 57 Db. In the networks on the base of the CAN C 2.0 technology, when the error counter reaches 256 in case of the concrete node, the shift Bus Off takes place, and in this work state the information transmitting is provided by the simplex mode of work [3]. There are many methods of data analything, but the traditional methods are not always be efficient in the case of the high level of transmitting noises, so the need of improvement of the current methods is always important [1,2,3].

One of such methods is the method of window spectrum estimation, which uses the mean estimation of the log spectrum of a signal. The main misfit of this method is decreasing of his implementation efficiency in the high noises environment. So, it is proposed to use the multiwindow mean estimation of the signal's log spectrum in order to get more precise estimation and increase the efficiency of thresholds methods of the signal processing. It is achievable by the means of the speed wavelet transformation which has tree-like structure and by the means of the parallel calculation's methods which are currently in the state of constant development. The last type of methods let decrease the duration of the calculations in many times. This form is the base of the enhanced methods of the spectrum's window estimation [4,5,6].

The goal of this work is increasing the efficiency of network's information processing in the environment that has the high level of noises by the means of the improvement of the current methods of analyses on the base of the orthogonal functions [7,8,9].

The improvement of the spectrum's multiwindow estimation

Choosing a window function depends on the many factors and should be carried out for all tasks separately [4]. This recommendations is applicable as for the one function analysis, so for multiwindow analysis. In order to choose the window of signal smoothing the one should assess the spectrum and the scale of the amplitude of the spectrum parts of a signal. When a signal has the spectrum components with the big amplitude and the frequencies of the components, that are important for us, differ significantly from the frequencies of the unimportant spectrum's parts, it is better to choose the steep slop smoothing window [10,11,12].

When a signal has the spectrum components with the big amplitude and its frequencies are close to the most important of them, smoothing window of the minimal level on the side petal should be chosen[5].

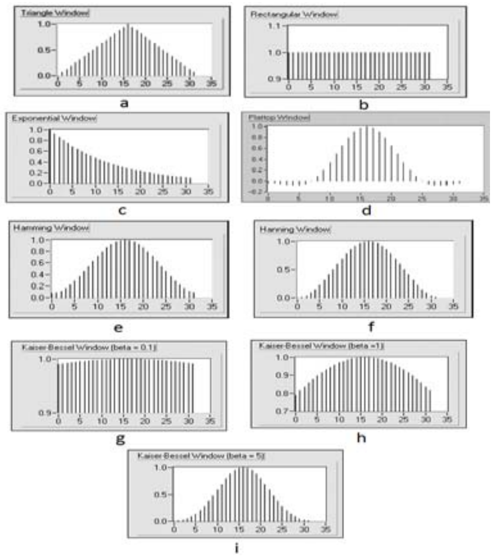

Fig.1. The discrete spectral characteristic of some window functions when a sample N = 32: a – a triangular window, b – a square window, c – a exponential window, d – a flat top window; e – the Hamming window, f – Hanning window, g – Kaiser-Bessel window (β = 0.1), h – Kaiser-Bessel window (β = 1), i – Kaiser-Bessel window (β = 5)

On the table 1 is showed the main features of the popular window functions. The signals in the industrial and computer networks look like the noised and distorted square impulses and in case of their estimation the Hamming window function, the sinusoidal function and the Kaiser-Bessel function are the best chose. The spectrum's characteristics of the most popular window functions are depicted on fig. 1.

Table 1. Comparing characteristics of the window functions.

Window functions	The maximal level of side petals (Db)	The slop of the side petals (Db/decade)	The level of the main petal when -3 Db	The level of the main petal when -6 Db	The equivalent strep of noise energy missing (ENBW)	Synchronic amplification (scale coefficient)	The error of the spectrum's amplitude estimation (Db)
Sinusoidal	-12	20	0.89	1.20	1.00	1.00	3.33
Hanning	-33	60	1.45	2.01	1.50	0.50	1.43
Hamming	-43	20	1.31	1.80	1.37	0.54	1.75
Blackman-Harris	-72	20	1.63	2.28	1.72	0.43	1.12
Blackman	-59	60	1.65	2.31	1.74	0.43	1.12
FlatTop	-45	20	2.93	3.57	3.78	0.23	<0.01

The window functions shown on the fig. 1 have the form (N – the quantity of calculations (window length), n = 0, 1, 2, …, N – 1, w – window meaning):

- a square window: $w(n)=\begin{cases}1, n\in[0,N-1]\\ 0, n\notin[0,N-1]\end{cases}$;
- Hamming window:
  $w(n)=0.5336-0.46164\cos(\frac{2\pi n}{N-1})$;
- Hanning window: $w(n)=0.5-0.5\cos(\frac{2\pi n}{N})$;
- a triangular window: $w(n)=1-\left|\frac{2n-N}{N}\right|$;
- a flat top window: $w(n)=\sum_{k=0}^{4}(-1)^{\frac{k}{a_k\cos(k\omega)}}$,
  where $\omega=2\pi n$, a_0 = 0,2155, a_1 = 0,4166, a_2 = 0,2772, a_3 = 0,0835, a_4 = 0,0069;
- an exponential window:
  $w(n)=e^{(\frac{n\ln(f)}{N-1})}=f^{(\frac{n}{N-1})}$, were f –*is* the final meaning of the frequency [6].

The main task of the signal processing is the attempt to get the more precise estimation of the main spectrum signal's value q. In order to do this, it is proposed to apply the wavelet transformation to assess the noise spectrum and the signal spectrum of the q component, using computed coefficients. In order to assess q in the abscissa $j_y k$ we use the next expression:

(1) $$q_{j,k}=\frac{1}{2^j}((\frac{1}{2R+1}\sum_{n=-R}^{R}c^S_{j,n+k})-q^n_j),$$

where j – the step's quantity of the transformation, R – the characteristic of the local window size, $c_{j,k}$ – the transformation coefficient of the noised signal's spectrum, q^n_j – the shift between the transformation coefficient and the noise.

The q^n_j can be presented like total value of all the noise transformation coefficients on the stage of process j. It is proposed to use specialized group of the orthogonal wavelets that have the low asymmetry in order to get the wavelet disintegration. This wavelets are orthogonal, have the low asymmetry and the effective realization. After the orthogonal transformation was provided, the mathematical expectation and the signal dispersion were not changing in the area of the transformation. From the other side, the low asymmetry's feature influences the proximity of the linear phase characteristic in such way, that the borders or the peaks have the lower dispersion in the area of transformation. When the $q_{j,k}$ is cleared, the appropriate root-mean-square declination σ_z of the function z can be found by the means of its coefficient. The cutting of the wavelet coefficient can be fulfilled by the next threshold coefficient

(2) $$\delta(i,k)=\sigma(i,k)\sqrt{2\log N},$$

where N – the number of the signal counting, $\sigma(i,k)$ – the root-mean-square deviation of the noise spectrum with the wavelet coefficient i and k.

The structure of the one window transformation of the adaptive threshold methods [7] is shown on the fig. 2.

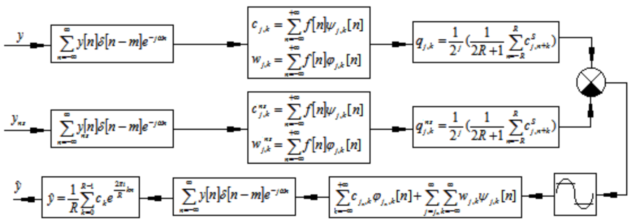

Fig.2. The one window transformation method's structure of the adaptive threshold methods' spectrum estimation

This structure can differ by the stages quantity of the different threshold methods, but to all this methods the Fourier window transformation is applied, for which the e fixed window function with the defined parameters is chosen. The incorrect choice of the window function can cause the significant error during the processing. The structure of the multiwindow transformation in case of the adaptive threshold method is showed on the fig. 3.

This structure differs from the structure showed on the fig. 2 by using the mean estimation of the L windows for the providing of the spectrum's estimation.

The threshold coefficient is adapted to the value of the multiwindow signal spectrum's local estimation because of the signal spectrum and noise spectrum ratio g_z is also adapted to this value. The proposed method of the signal processing is based on the adapted noise clearing and its scheme is showed on the fig. 3:

1) The estimation of the noise power (for example , the noise caused by non-informative source), and its spectrum characteristic's estimation are showed on the fig. 4.

2) The operation's repetition for each window of the noised signal:

conducting the multiwindow estimation of the signal's spectrum y, using (3)

(3) $$y=g_z y_z,$$

where y_z – the spectrum of the signal.

The calculation J of the discrete wavelet transformation stages $\{c^{s}_{j,k}, w^{s}_{j,k}\}$ and the log multiwindow spectrum estimation $\{c^{ls}_{j,k}, w^{ls}_{j,k}\}$ by the means of the low asymmetry wavelet coefficients.

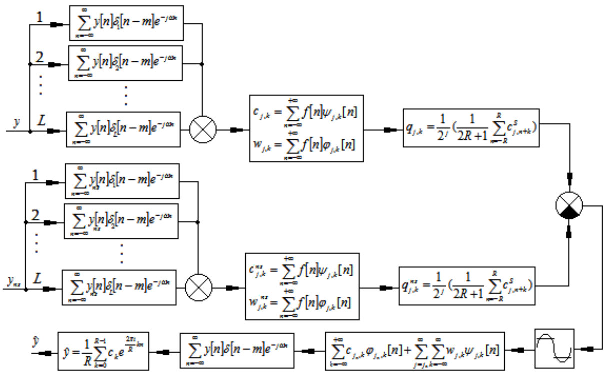

Fig.3. The structure of the multiwindow transformation in case of the adaptive threshold method of signal's spectrum estimation

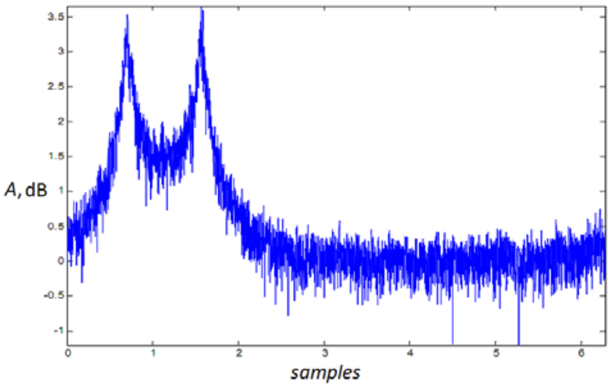

Fig.4. The log estimation of the test signal's spectrum [8]

3) the valuation of $q_{j,k}$ by the means of (1) and the calculation σ_z.

4) the subtraction of $w^{s}_{j,k}$ from (2).

5) the inverse discrete wavelet transformation of the noise cleared coefficients $\{c^{ls}_{j,k}, \widehat{w}^{ls}_{j,k}\}$.

6) the renewed signal is exponentially transformed and the signal's spectrum of the wavelet coefficient $g(w)$ is calculated by the means of (4) or (5):

(4) $$\log \hat{S}^{MT}(k) = \log S(k) + \log \nu(k),$$

(5) $$Z(k) = \log \hat{S}^{MT}(k) - \psi(L) + \log(L),$$

where: $\hat{S}^{MT}(k)$ – the multiwindow function of the spectral estimation; $S(k)$– the real spectrum; $\nu(k)$– the noise; $\psi(L)$ – the dispersion.

7) getting the signal's estimation $\hat{y}$ на on the base of the discrete Fourier transform and the wavelet transformation $g(w)$ of the signal y;

8) the signal's renewal, using the inverse speedy Fourier transform together with the integration and composition methods.

The analysis of the improved multiwindow method's efficiency on the base of the conducted numeric experiments

The estimation of the enhanced multiwindow method's efficiency is fulfilled by the modeling in the virtual environment provided by LabView. The efficiency of the estimation is defined by the means of comparing the spectrum estimation preciseness applying the different window functions to the test signals that have a priory known spectrums.

The test signals look like the consequence of the square impulses together with their consequence after the influence of the white noises, the spectrum of which is also well-known in this experiment.

The white noise was provided by the system, which scheme is shown on the fig. 5.

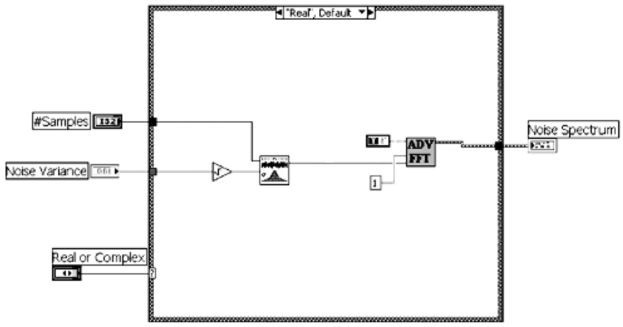

Fig.5. The system of the white noise creating

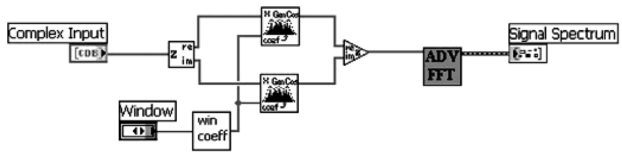

Fig.6. The signal transformation by the means of one window Fourier transform function

The dispersion value or the root-mean-square deviation of the spectrum estimation from the real value comprises the method's efficiency: the less is the deviation of the spectrum's estimation the more is the efficiency of the adaptive threshold method which uses this type of estimation. So, the traditional methods of the log estimation' smoothing of the multiwindow spectrum [9], by the means of some kind of the popular threshold coefficient[10], very often just smooth the big values of the amplitude but cannot remove all little accidental picks.

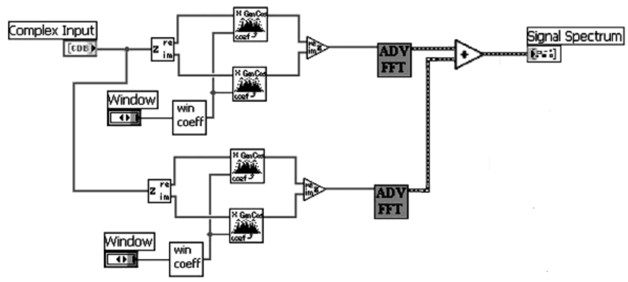

Fig.7. The signal's transformation by the means of two window functions and their mean estimation

On the fig. 6 is shown the scheme of the spectrum estimations' comparing when one window function is applied.

The window function is chosen among the other options on the float board. In a similar way the one can do the transformation of some different window functions and use the mean estimation of the signal's spectrum. On the fig. 7 is shown the way of finding of signal's spectrum estimation by the means of the mean estimation of two window functions.

On the fig. 8 is shown that the root-mean-square deviation σ_z changes, when the value of the main signal's spectrum q from 2 to 6 windows changes too.

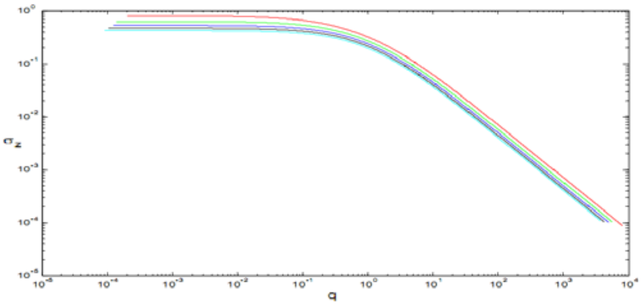

Fig.8. The ratio between the value of the main signal's spectrum q and the root-mean-square deviation σ_z of the function $z = \log(t + q)$ for: – 2 windows; – 3 windows; – 4 windows; – 5 windows; – 6 windows

The graph on the fig. 8 shows that the root-mean-square deviation σ_z decreases from 1 to 0.9-0.5, or 10-50% less, and this let us conclude that the preciseness of the spectrum's estimation increases.

The adapted threshold coefficient that can be corrected according to the estimation's value of multiwindow signal's spectrum gives the more technical possibilities.

The comparing of the adapted threshold efficiency is fulfilled by the means of the one window and multiwindows spectrums estimations during the clearing of the signal[8].

On the test signals that have the form of the two square impulses the white noise of the amplitude $A = 0{,}2$ V was put, so the ratio signal/noise was $h = 14$ Db. The noised signal is showed on fig. 9.

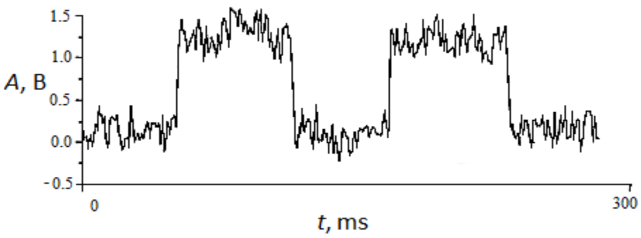

Fig.9. The test signal under the influence of the white noise T, $h = 14$ Db

The adapted threshold method is used for the processing of this noised signal.

On the fig. 10 is revealed the result of the Hanning window function implementation during the spectrum's estimation by the means of the adapted threshold method.

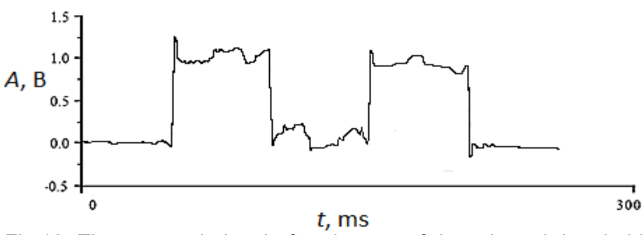

Fig.10. The renewed signal after the use of the adapted threshold method with the spectrum's estimation by the means of Hanning window, $h = 21$ Db

The ratio signal/noise increases up $h = 21$ Db.

On the fig. 11 is showed the result of the signal processing by the means of two window functions: Hanning window function and the sinusoid window function.

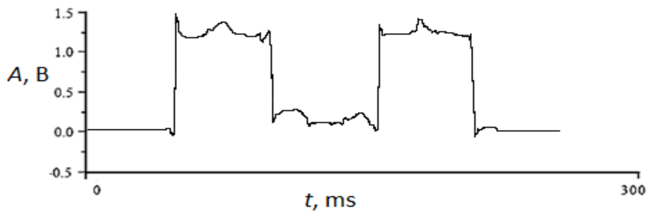

Fig.11. The renewed signal after the use of the two window spectrum's estimation by the means of Hanning window and the sinusoid window, $h = 25$ Db

The ratio signal/noise increases up to $h = 25$ Db.

On the fig. 12 is shown the result of the signal processing by the means of the adapted threshold methods when the three window functions are applied: Hanning window, the sinusoid window function and Kaiser-Bessel window function ($\beta=1$).

The ratio signal/noise increases up to $h = 28$ Db.

As we see on the fig. 10, 11, 12, the increase of the window functions quantity during the spectrum estimation leads to the increase of the adapted threshold methods' use efficiency and the ratio signal/noise increase. But the time of processing also increases according to the quantity of the applied functions.

The dependency between the processing time and the quantity of the applied functions has the linear-log character.

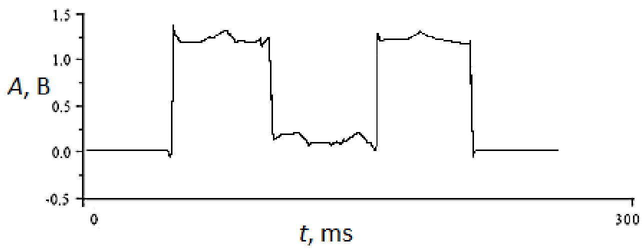

Fig.12. The renewed signal after the implementing of the three window spectrum's estimation by the means of Hanning window, the sinusoid window and Kaiser-Bessel ($\beta=1$), $h = 25$ Db

But the window transformation has no complicated operations[11], so this disadvantage does not significantly influence the speed of the data processing and this issue is not a very important question in the case of the signal processing in the environment with the high level of the noises.

The improvement of the spectrum's multiwindow estimation in the case of adapted threshold method shows its efficiency in contrast to the one window type of the spectrum's estimation. The window functions should be chosen according to their transformation properties. The best results have been gotten in case of applying the different types of window functions. The preciseness of the estimation increases during the implementation of each supplementary window function but for all the windows this increase will be less than after the previous function implementing.

The efficiency's experimental verification of the enhanced method of the multiwindow spectrum's estimation by the means of network modeling program can

In order to check the efficiency of the improved method of the multiwindow signal's spectrum estimation in case of the real network in the highly noised environment, the authors use the program of network's signals modeling CAN, developed by «Marafon»[12] on the base of the

National Instruments technologies. The CAN network, in particular CAN 2.0A, is used in the transport systems for data transmitting from the sensors to the board and from the board computers to the service machinery computers, so that the error's probability should be negligible and the distorted transmitting should be impossible. The data transmitting modeling program carry out the differential noised signal transmitting with the different speed of the sending using the cycle redundancy code and do not use the noise clearing methods during his work. The data transmitting efficiency is estimated by the means of the errors quantity calculation that was improved by the cycle redundancy code and the quantity of the lost bits during the repeated packet's transmitting. The method of the multiwindow spectrum's estimation is implemented in this program by the means of the software realization (C++, DLL file). After the data transmitting the signal is taken dawn in the service log file, where the incoming data for the method of multiwindow spectrum's estimation is keeping. Choosing the window function is released algorithmically. The one window spectrum's estimation is the particular case of the multiwindow spectrum's estimation. This method is popular and is compared with the enhanced methods of the multiwindow estimation [13-16].

The particular program saved in an exe-file launches this DLL-file, carry out the signal's spectrum clearing in order to the scheme shown on the fig. 3, and saves the result of the method's work in the rewritten log-file. The cleared signal is processed by the «Marafon» software. The errors type I are classified like the sum of corrected bits in the 1000 packets' message, and the errors type II are classified like the quantity of bits that should be transmitted after the first try.

The windows of receiving and sending sides are shown, in proportion, on the fig. 13 and the fig. 14.

On the fig. 13 is showed the sending window of the message's parameters of CAN and the signal's oscillogram according to the formed message with defined parameters in the border of CAN 2.0A and CAN 2.0B standards [2], which are differing in proportion to their frame's form and the white noise level. On an oscilogram can be showed the signals CAN-H, CAN-L and the differential signals (CAN-H - CAN-L).

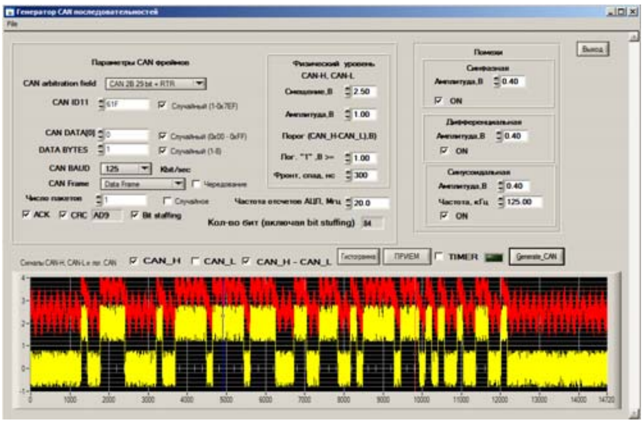

Fig.13. The CAN's message creation on the sending side

The defined parameters influence the levels of the common-mode, differential and sinusoid noises, the transmitting speed, the type and the form of the frame, the number of data's bits.

On the fig. 14 is presented the image of the receiving window. The oscillogram of received signal, the recognized signal and the meaning of the frame's service bits (for example, the error's bits CRC) are showed. The sending window has a launch button of the window of signal's CAN spectrum analyzer. By analogy, this window can show the amplitude's spectrums of the CAN-H, CAN-L signals and the CAN-H - CAN-L difference's signals.

On the fig. 15 is showed the CAN-H, CAN-L, CAN-H - CAN-L signal's spectrum. The noises levels is 0,2 V or 14 Db.

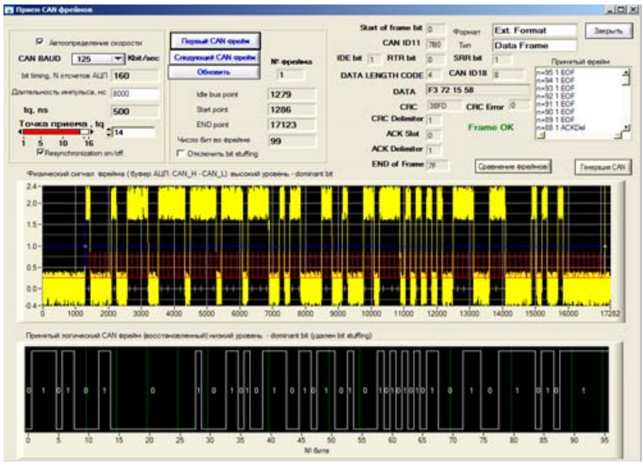

Fig.14. Processing and analyzing the CAN's signal on the receiving side

The defined parameters influence the levels of the common-mode, differential and sinusoid noises, the transmitting speed, the type and the form of the frame, the number of data's bits.

On the fig. 14 is presented the image of the receiving window. The oscillogram of received signal, the recognized signal and the meaning of the frame's service bits (for example, the error's bits CRC) are showed. The sending window has a launch button of the window of signal's CAN spectrum analyzer. By analogy, this window can show the amplitude's spectrums of the CAN-H, CAN-L signals and the CAN-H - CAN-L difference's signals.

On the fig. 15 is showed the CAN-H, CAN-L, CAN-H - CAN-L signal's spectrum. The noises levels is 0,2 V or 14 Db.

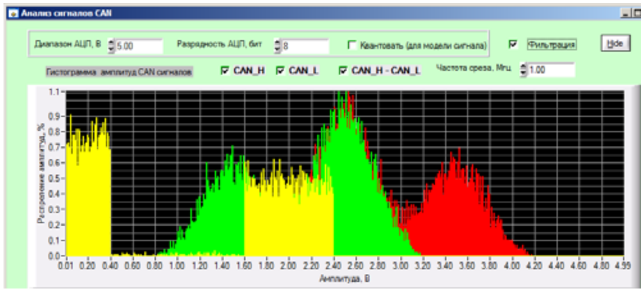

Fig.15. The amplitude of CAN-H, CAN-L, CAN-H - CAN-L signal's spectrum when the obstacle's level is 0,2 V

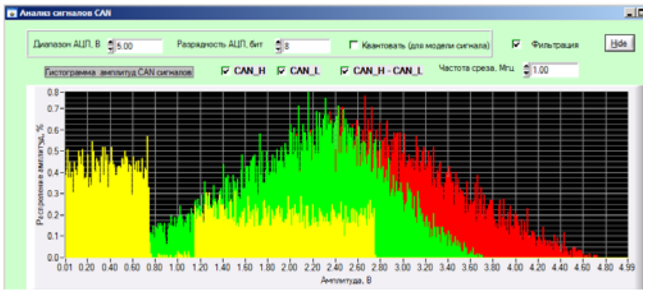

Fig.16. The CAN-H, CAN-L, CAN-H - CAN-L signal's spectrum when the level of the noises is 0,4 V

We can see the significant dispersion of the amplitude's spectrum on the fig. 15.

On the fig. 16 is shown CAN-H, CAN-L, CAN-H - CAN-L signal's spectrum when the level of the noises is 0,4 V or 8 Db.

In this case, the amplitude's spectrum has more significant dispersion than in the previous case.

According to the standard norms [3] the noises level that is less than 20 Db is considered to be significant and it is impossible to provide reliable work in this circumstances. The signals modeling on the CAN networks show that transmitting is possible when the signal/noise level is more than 14 Db. The applying of the methods of the multiwindow spectrum's estimation let transmit the data when the signal/noise level is more than 8 Db. The receiving window has such options like the received and transmitted signal's comparison, the synchronizing modeling, the data transmitting speed determining, the error correcting. On the fig. 17 is showed the comparison of the received and the transmitted signals.

As we see from the picture, the messages match each other, but there is the time shift like the result of the imperfect synchronization

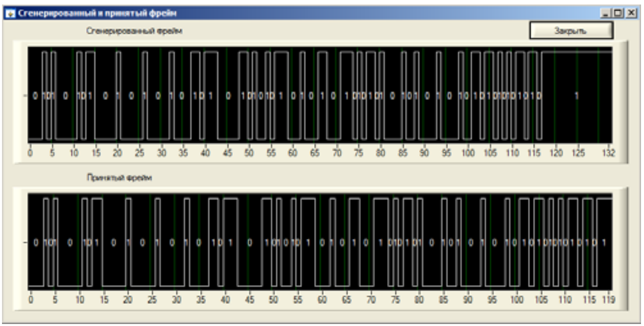

Fig.17. The received and transmitted signals comparison

This happening does not influence the receiving of the next frame, because its synchronization takes place independently. In this software the received and the transmitted messages do not have any difference, because the wrongly interpreted bits are corrected, but the whole frame can be lost because of the synchronization fail.

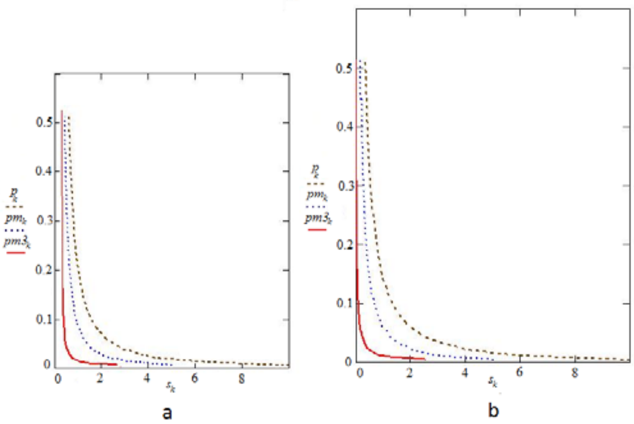

Fig.18. The probability of the errors of type I (a) and type II (b) in the case of the multiwindow spectrum's estimation depending on the signal/noise ratio s: p – the errors' probability without the method applying; pm – the errors' probability with one window method applying i; $pm3$ – the errors' probability with tree window method applying.

When it is impossible to correct the all errors (too much unrecognized bits), the second try of the frame transmitting is happen, and the error bit ErrStaffBit changes his meaning from FrameOK to ErrorFrame. Because of the big code length the probability of the error recognizing is close to 100%, but the second try slows the transmitting speed.

So, the message about impossibility of speedy transmitting can be interpreted like the information about error happening. The software has the received data saving possibility in the form of archived log-file. In the case of the automatic data transmitting there is the possibility of the statistical data processing which shows the efficiency of a method in the process of data transmitting. In this case the accepting of the frame's recessive bit like logic «0» is the error type II, and the accepting of the frame's dominant bit false logic «0» is the error type I (fig. 18).

The errors of type I and type II are received during the experimental work is shown on this image. From the graphs we can see that when the signal/noise ratio decreases, the frequency of both types errors occurring increases exponentially. The errors type I and type II increasing is the same, but there is the significant scale difference because the errors type II can happen and the packet can be lost when the middle level of noises is and the error type I can happen when there is even the low level of noises.

Conclusions

The theoretical researches in the area of the signal processing methods of the distributed computer systems have been fulfilled by the means of modeling and experiments. The newly enhanced methods let raise the efficiency and lower time consumption of the current signal processing systems, so the goal of this work is reached. During the fulfillment of this researches the authors use the science methods the authenticity and preciseness of which are proved by the different science works [4,7,11], and the negligible divergence between the theoretical and practical results proves their adequate implementation to this type of tasks.

Authors: *Ph.D., Senior Lecturer of Automatics and Information-Measuring Techniques Department Kulyk Yaroslav, Vinnytsia National Technical University, Khmelnytsky Hwy, 95, 21021 Vinnitsa, Ukraine, E-mail: Yaroslav_Kulik@i.ua, Ph.D., Senior Lecturer of Electronic and Nanosystems Department Knysh Bohdan, Vinnytsia National Technical University, Khmelnytsky Hwy, 95, 21021 Vinnitsa, Ukraine, E-mail: tutmos-3@i.ua, Senior Lecturer of Automatics and Information-Measuring Techniques Department Ivanov Yuryy, Vinnytsia National Technical University, Khmelnytsky Hwy, 95, 21021 Vinnitsa, Ukraine, E-mail: Yura881990@i.ua Ph.D., docent Anatolii V. Poplavskyy, Vinnytsia National Technical University, Khmelnytsky Hwy, 95, 21021 Vinnitsa, Ukraine, E-mail: Yura881990@i.ua; PhD., Prof. Andrzej Kotyra, Lublin University of Technology, Institute of Electronics and Information Technology, Nadbystrzycka 38A, 20-618 Lublin, Poland, e-mail: a.kotyra@pollub.pl; M.Sc. Nataliya Denissova, East Kazakhstan State Technical University named after D.Serikbayev, email: nata69_07@mail.ru; M.Sc. Gulzat Ziyatbekova, Al-Farabi Kazakh National University, Almaty, Kazakhstan, email: ziyatbekova@mail.ru.*

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