INFORMATICS

Signals processing of guard system in the wavelet domain

I. Ya. Tyshyk[1], Yu. K. Gruzdieva[1], M. V. Marchuk [1,2]

[1]National University «L'viv Polytechnic», L'viv, Ukraine
[2]Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, NASU, L'viv, Ukraine

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Abstract. This article is aimed at design and development of the new optimal approaches to analyze and process the reflected signals of guard systems to provide for detection of object's motion at a high level of reliability and noise robustness. The process wideband signals of guard systems transformation directly in the wavelet domain has been investigated for various basis functions, decomposition depths, and noise levels, which resulted in the definition of recommendations and principles for selection of the most efficient methods for processing of such signals.

Keywords: *wideband signals, guard systems, basis wavelet function, wavelet domain, decomposition depths.*

Introduction. In theory of communication, navigation, radio and hydro location, in alarm systems and in solving many other problems it is necessary to receive and use the evaluation of frequency-time parameters of the received signals and therefore measure their frequency, time or phase shift. The accuracy and noise robustness of the system depends on the efficiency of the algorithms in the processing of the received signals, reaching errors minimization of assessments of frequency-time parameters. Theoretically potentially the best estimates are obtained on the basis of maximum likelihood function, but its implementation complicates the structure of correlation and multichannel devices [1–3].Therefore, in practice, widespread devices that use simplified algorithms, increasing their efficiency are the main subject of study. The most common assessments of the frequency-time parameters of signals in practice are implemented by digital devices that provide filtering the signal and form an integrated assessment of the results of averaging. Improving the accuracy and noise robustness of devices with different operating conditions is an important task for future research.

It is known that the use of wideband signal models for radar systems has several advantages over narrowband models (detection moving small objects against the background of large stationary object, improving the reliability of detecting of moving objects, recognizing bulky objects, providing better resolution of closely spaced objects, increasing the accuracy of estimation of the distance to the object location, etc.).The efficiency of broadband processing in them depends largely on the area representation of the emitted and received signals. Because the evaluation of the quality of measurements in such cases essentially depends on the resolution of the analyzed signals, as well as the noise robustness of the selected transformation, the most beneficial and informative in this case is the use of time-frequency form of presentation of these signals and their subsequent processing in this region [4].

Analysis of studies and publications. The use of models of narrowband signals by radio wave motion detector in alarm systems has certain features associated with the fact that when approaching an object in the controlled area of space in the direction of the receiver, the width of the spectrum of the reflected signals from the presence of the Doppler effect increases concerning the width of the radiated spectrum signal. Thus, the work of such devices is typically performed under the influence of external and internal noises; their energy spectrum is predominantly linear, narrowband and located in the area of useful signals [5,7].This reduces the stability of the radio wave of alarm systems to false positives. Increasing in some degree of resistance to false positives is performed by well-known methods, usually by lowering the reliability of the detection of moving objects in a controlled area of space. In these radio wave devices of security systems, during the choice of an appropriate signal probing, it is looking for a compromise between these parameters.

Broadband short-pulse signals of sensing allow significantly improving the resolution and accuracy of measuring the distance to the object of observation, to reduce the «dead zone» system, increase its resistance to all kinds of passive noises and simplify the monitoring of the movement of an object against a background of powerful reflections from stationary objects. Mainly the methods of correlation and correlation filter of the processing reflected signals are used to select parameter of information from them [5, 6].However, the efficiency of these methods is lost during non-compliance with high requirements for linear frequency deviation of these emitted signals and inability to make qualitative and reliable evaluation of the reflected signals within their wide frequency range on the basis of these methods, it is resulting in deterioration of the reliability of the detection of moving objects corresponding devices of guard systems.

Wavelet transform is a promising technique for processing signals with the level differences. The works [4-8, 10] shows that wavelet filtering is optimal option for signals with a priori unknown form. To process the signals which have leaping their average value (for example, rectangular pulses), the work [9] proposes to use the method of adaptive threshold that allows partially keeping a sharp front pulse, which greatly reduces its errors of time location. In work [11] an alternative method to improve the accuracy of distance measurement of sensing object, based on the total energy by wavelet coefficients of probing and reflected signals, is proposed. For this method received values of wavelet coefficients of the probed and reflected signals are compared with each other, resulting the part of information of the distance estimate to the object of observation is obtained. Considered method is the most effective for a small distance of measurement, in which the level of received signal is slightly different from the level of radiation.

It is known that the wavelet transform is a handy tool for adequate representation of signals with localized frequencies, because the elements of its basis are localized and have a moving window of time-frequency. Due to the constant change of window size wavelet transform can provide proportional resolution in each frequency band, which allows creating fractal window with constant resolutions of bandwidth, thus it becomes possible to analyze and compare the differences of signals. Thus, the analysis and processing of short (broadband) signals of guard systems with the aim to improve their noise robustness and reliability of the detection of moving objects are the main field of application of wavelet transform.

The purpose of investigation. This article is aimed at design and development of the new optimal approaches to analyze and process the reflected radar sounding signals, and to create mathematical models, algorithms and system designs of digital converters to provide detection of object's motion at a high level of reliability and noise robustness. Based on the results of the analytical research and computer modeling, the process of wideband signal transformation directly in the wavelet domain has been investigated for various basis functions, decomposition depths, and noise levels, which resulted in the definition of recommendations and principles for selection of the most efficient methods for processing of sounding signals.

Problem statement. To improve the noise robustness of security alarm systems and improving their reliability of detection of moving objects, the aim is developing of new and effective approaches to the study of broadband echo signals, researching their transformation process directly in the time-frequency (wavelet) region for various basic functions, decomposition depths and noise levels, it gives opportunity to develop recommendations for choosing the most effective option for processing these signals.

Signal processing of guard systems in the wavelet region. Since the theory of wavelet transform can effectively implement broadband processing, based on this it is advisable to analyze wideband signals and sensing systems that form them.

During wavelet transformation emitting signal is served as broadband, its functional dependency decomposes into a set of elementary components. Such components are found through the correlation between the input signals and some basic functions that differ from the original prototype by their own bias and scale. Decomposition of the radiated signal for this basic wavelet function $g(x)$ is defined as follows [8, 9].

$$(W_g s)(a,b) = \langle s, g_{a,b} \rangle = |a|^{-\frac{1}{2}} \int s(t) g^*((t-b)/a)\,dt, \quad (1)$$

where $s(t)$ – emitting signal; a – time scale; b – time delay or offset.

According wavelet decomposition of the received signal can be written

$$(W_g s')(a,b) = \langle s', g_{a,b} \rangle = |a|^{-\frac{1}{2}} \int s'(t) g^*((t-b)/a)\,dt, \quad (2)$$

where $s'(t)$ – the received signal.

Thus, obtained sets of wavelet functions are new presentation of location of signals in wavelet field. The values $(W_g s)(a,b)$ and $(W_g s')(a,b)$ are calculated for each value scale and bias, which allows considering the wavelet transform as analyzing filter which helps to perform the signal decomposition into individual components. Obtained components at different scales can be operated in place of the original signal. This presentation allows efficient filtering of noise in received signal with rejection of «noise» component in further and receives results directly in the wavelet field.

On the basis of obtained mathematical models and algorithms of wavelet transform of broadband signals locations, appropriate structures of processing and evaluation of signals directly in wavelet area are proposed in the work that allows increasing robustness and efficiency of detecting of moving objects by locating security systems.

During using locations of short-term (broadband) pulse signals by security systems, informative parameter is usually the time of receipt of the reflected signal relative to some standard. Discrete sequences of reflected signal $s[k]$ come to the system of wavelet filters (WF) proposed structure of wavelet converter (Figure 1). Each level of transformation provides decay of input sequence corresponding pair of WF.

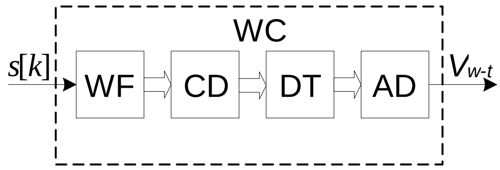

Fig. 1. The structure of the wavelet-converter (WC)

The sets of wavelet coefficients are formed on the output of WC $d_{j,n}$, which are represented the echo signal in the time-frequency domain. The above mentioned sets through the unit of correction displacement (CD), which takes into account the difference of time offset of wavelet components of the echo signal at each level of decomposition, come to the device of threshold DT, which is made at each level of threshold the values of wavelet coefficients according to a universal criterion [4–6]. The sets of wavelet coefficients come to adder (AD), resulting value of wavelet components of the echo signal is formed on the output $V_{\text{w-t}}$:

$$V_{\text{w-t}} = c_{J+1} + \sum_{j=1}^{J} d_{j,n}, \quad (3)$$

where j –the level of decomposition (j = 1,2,3,..., J; n = 1,2,3,..., 2^j); c_{J+1}– the low pass coefficient.

The resulting value of wavelet components of the next echo signal $V'_{\text{w-t}}$:

$$V'_{w-t} = c'_{J+1} + \sum_{j=1}^{J} d'_{j,n}. \quad (4)$$

Later (Figure 2) only plural components $V_{\text{w-t}}$ and $V'_{\text{w-t}}$ are processed, the total value of which exceeds a threshold of detection λ_{k}, or equal to [10].

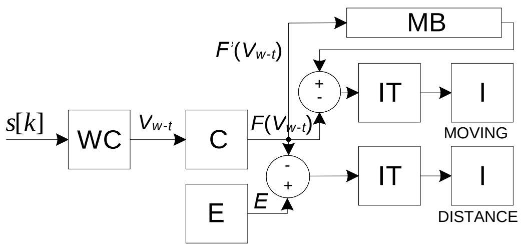

Fig. 2. The structure of the process of computer simulation of processing of the echo signals to guard systems

Amplitude values $V_{\text{w-t}}$ are the basis of the formation of functional dependence $F(V_{\text{w-t}})$ corresponding comparator (C).Formed normalized signal of rectangular shape with C comes to the device of difference that generates the informative value of output-difference, which is the basis of formation the evaluation of distance to the object's location in the time domain $D = E - F(V_{\text{w-t}})$, where E –reference value from generated block (E), which submits to the device of difference. In addition, $F(V_{\text{w-t}})$ is stored in memory block (MB).Signal of difference is sent to the device of integration (IT), where informative value is displayed on the indicator of range (I).

The amplitude value of another reflected signal V'_{w-t}, received by (4), underlies the formation of functional dependence $F(V'_{\text{w-t}})$. The signal $F(V'_{\text{w-t}})$ from the C and the previous normalized signal generated from MB at the same time come to the device of difference that generates the informative value of output-difference S regarding the availability motion of the object of observation:

$$\text{S} = F(V'_{w-t}) - F(V_{w-t}). \quad (5)$$

Difference signal is sent to IT; from there the informative value is displayed on the moving indicator I.

Obtained informative values of D and S are the basis the formation of the corresponding alarm system.

In some papers [5–8] it provides a better representation with respect to traditional methods of processing, evaluation by the relevant security systems the presence of moving objects in a controlled zone of sensing space in a priori unknown form of the reflected signal, and the type of noise. It should be noted that the accuracy of the offset of wavelet components of the reflected signal relative to the wavelet components of radiation (reference) signal will depend on the choice of the depth of decomposition of the researched signal and the type of basic wavelet functions that used in the time-frequency (wavelet) transformation.

In the work appropriate studies depending on the accuracy characteristics of the usage of wavelet basis functions and the number of decomposition levels (6 to 8) were conducted. At the same time the impact on the accuracy of signal transformation of location changes in the duration of the leading edge of the received signal (15%, 30% and 50% of the pulse duration) was estimated.

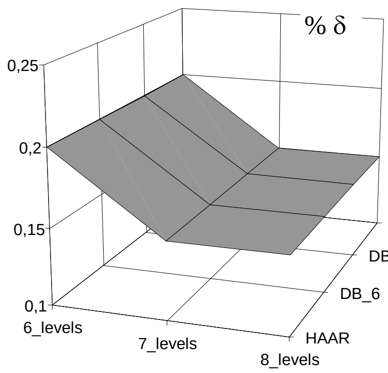

Fig. 3. Dependence of consolidated errors of transformation from using basic functions Haar (HAAR), Daubechies 6-th, 8-th, 10-th order (Db6, Db8, Db10), at 15 percentages of tightening of the leading edge of the envelope of the received signal and imposed on him 15 percentages of noise with Gaussian distribution

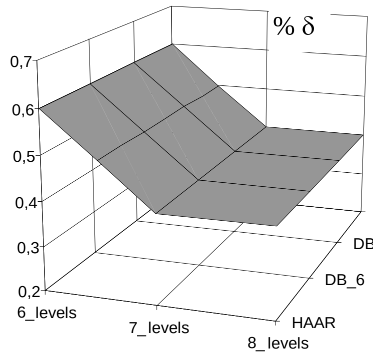

Fig. 4. Dependence of consolidated errors of transformation from using the Haar basis functions (HAAR), Daubechies 6-th, 8-th, 10-th order (Db6, Db8, Db10), at 30 percentages of tightening the leading edge of the envelope of the received signal and imposed on him 15 percentages of Gaussian distribution noise

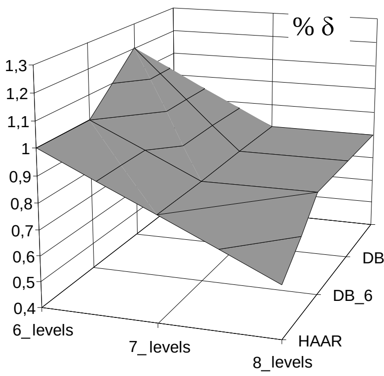

Fig. 5. Dependence of consolidated errors of transformation from using the Haar basis functions (HAAR), Daubechies 6-th, 8-th, 10-th order (Db6, Db8, Db10), at 50 percentage of tightening the leading edge of the envelope of the received signal and imposed on him 15 percentages of Gaussian distribution noise

Maximum was chosen from the 26 obtained values of consolidated errors for each of the combinations of study. The obtained dependences are shown in Fig. 3, 4 and 5. Studies show that consolidated error of transformation is to a greater extent affected by the depth of decomposition and the degree of tightening of the leading edge of the envelope of the received signal. At the same time, the consolidated error of transformation is less dependent on the type and order of used basis of wavelet functions.

MATLAB R2009a software package was used for modeling the procedure of processing of broadband reference and reflected signals of wavelet transformation.

Conclusion. To improve the noise robustness of security alarm systems and their reliability of detection of moving objects, the process of transformation directly into time-frequency (wavelet) region for various basic functions and levels of decomposition depths of noise was investigated, new approaches to the study of broadband echo signals and recommendations for choosing the most effective option for processing these signals were developed.

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Опрацювання сигналівсистем охорони у вейвлет-області

І. Я. Тишик, Ю. К. Груздєва, М. В. Марчук

Анотація: Стаття присвячена розробленню нових ефективних підходів щодо опрацювання відбитих сигналів систем охорони для забезпечення ними високої завадостійкості та достовірності виявлення рухомих об'єктів. Досліджено процес перетворення широкосмугових сигналів охоронних систем безпосередньо у вейвлет-області для різних базисних функцій, глибин декомпозиції та рівнів шумів, що дозволило розробити рекомендації для вибору найбільш ефективного варіанту опрацювання таких сигналів.

Ключові слова: *широкосмуговий сигнал, системи охорони, базисна вейвлет-функція, вейвлет-область, глибина декомпозиції.*

Обработка сигналов систем охраны в вейвлет-области

И. Я. Тишик, Ю. К. Груздева, М. В. Марчук

Аннотация: Статья посвящена разработке новых эффективных подходов к разработке отраженных сигналов систем охраны для обеспечения ими высокой помехоустойчивости и достоверности обнаружения движущихся объектов. Исследован процесс преобразования широкополосных сигналов охранных систем непосредственно в вейвлет-области для различных базисных функций, глубин декомпозиции и уровней шумов, что позволило разработать рекомендации для выбора наиболее эффективного варианта обработки таких сигналов.

Ключевые слова: *широкополосный сигнал, системы охраны, базисная вейвлет-функция, вейвлет-область, глубина декомпозиции.*