PERFORMANCE STUDY OF AN ALGORITHM FOR PROCESSING A PACKET OF REFLECTED ULTRASHORT PULSES UNDER A PRIORI UNKNOWN WAVEFORM AND GAUSSIAN NOISE CONDITIONS

ИЗСЛЕДВАНЕ РАБОТОСПОСОБНОСТТА НА АЛГОРИТЪМ ЗА ОБРАБОТКА НА ПАКЕТ ОТРАЗЕНИ СВРЪХКРАТКИ ПРИ АПРИОРНО НЕИЗВЕСТНА ФОРМА НА СИГНАЛА И В УСЛОВИЯ НА ГАУСОВ ШУМ

MSc .Eng. Uzunova S. S
Technical University Sofia, Bulgaria
suzunova@tu-sofia.bg

Abstract: In this study, an analysis of the results obtained after simulation studies of the synthesized modified algorithm with a priori unknown form of the ultrashort pulses (USPs) reflected from a point target, and when operating in Gaussian noise conditions, has been carried out. Proposals for the boundary conditions for the optimal operation of the algorithm have been made. The Prony method has been used to determine the moment of arrival of the reflected signal and estimate the complex components of the USP amplitude. The study is a continuation of the publication devoted to the synthesis of a modified algorithm for processing a bunch of USP pulses reflected from a point target.
Keywords: modified algorithm; ultrashort pulses (USP), reflected signal discretization, Prony method.

1.Introduction.

The algorithm proposed in the previous publication for calculating the arrival time of the ultra-short reflected pulse was synthesized under the condition that only reflected signals are considered and noise samples, which are always present in the input signal under real conditions, are not accounted for. Under "noise component," it will hereafter be assumed that the input sequence contains "white" (Gaussian) noise with a one-sided noise power spectral density – N_0. In this case, the estimation of the time moment – τ, will be obtained with a certain error, which will depend on the signal-to-noise ratio (S/N).

2. Prerequisites and ways to solve the problem.

In the first stage, it was proven that the chosen approach is suitable for calculating and estimating the amplitudes (also presented in complex form) of the reflected ultra-short pulses.

In some publications, the measurement of the arrival time of a reflected USP is solved using the MUSIC method. Studies show that other known methods can also be used – such as the Annihilating Filter, Prony's method, etc.. Further in this study, Prony's method will be used. This is necessary for the following three reasons:

1.It is not possible to use analytical dependencies for synthesizing a sequence of mathematical procedures when determining the characteristics of the amplitudes of USPs from the input packet of reflected signals.

2. During the synthesis of the modified algorithm and the analysis of its effective performance, restrictive conditions were imposed regarding:

- the estimation only of the conditional time shift, and
- the dispersion of time shifts in the observation period, averaged for the input packet of reflected pulses .

3.Prony's method was used for direct determination of the arrival time of the reflected USP. These arguments necessitate that the analysis of the estimation effectiveness be computer-modeled in a Matlab environment.

3. Solution to the studied problem.

As a starting point for the modeling, the main mathematical expressions from the synthesis of the modified algorithm will be recalled:

- An USP with a bell-shaped form of the type - $s(t,\tau) = Ae^{[-\alpha^2(t-\tau)^2]}$ where $t \in [0;T]$ was used as a model of the input signal reflected from a point target.

- Normalized time value - $\tilde{t} = \frac{t}{T}$ and normalized arrival time of the reflected pulse - $\tilde{\tau} = \frac{\tau}{T}$ were introduced .

-The result of these introductions is the representation of the input signal in the following form $s(\tilde{t},\tilde{\tau})= Ae^{[-\tilde{\alpha}^2(\tilde{t}-\tilde{\tau})^2]}$ where $\tilde{t} \in [0;1]$, a $\tilde{\alpha} = \alpha T$;

- The expression illustrating the impulse response of the Nyquist filter was similarly transformed, taking into account the following dependencies - $\omega_c T = 2\pi M, M \geq 2$

- During the modelling itself, a noise component, in the form of uncorrelated noise with dispersion - σ^2, was added to the signal function.

For conducting the simulation studies, the following input parameters for the respective quantities were used:

$-\tilde{\alpha}$ = 200, 300, 400;

− Low-Pass Filter (LPF) Nyquist parameter − $\beta = 0.1 \div 0.9$ with a step of – 0.1, i.e., β = 0.2; 0.3; 0.9;

− Signal-to-noise ratio (S/N - q) – q = 5÷40, with a step of 5.

After conducting the simulations, the following conclusion can be drawn:

The "estimation of the displacement" approaches 0, i.e., the phenomenon of "absence of displacement" is observed, which corresponds to an unambiguous measurement of the arrival time of the reflected ultra-short pulse, and thus an unambiguous determination of the distance to the observed object.

This "phenomenon" is especially pronounced at high S/N ratios – in the order of q ≥ 20 – 50. To visualize the dependence of the error allowed in estimating the time displacement, a graph is shown in Fig. 1.1, where the obtained graphs, numbered 1 - 5, are displayed for different values of M and N, respectively. The horizontal axis shows different S/N ratios with a step of % dB, and the vertical axis shows the allowed error in determining the normalized arrival time of the reflected signal. It should be clarified that curves 1 and 2 were obtained with the same "smoothing coefficient" β = 0.55 for the Nyquist LPF.

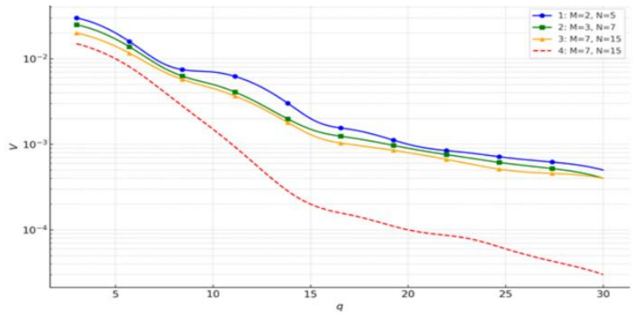

Fig. 1. Dependence between variables q and V for different values of parameters M and N.

Four series of data are visualized with smoothed lines and different colors for better readability. The graph is on a logarithmic scale on the Y-axis. Series 1 (blue line, M=2, N=5) shows the highest values of V, while Series 4 (red dashed line, M=7, N=15) has the lowest values, which suggests better model efficiency or stability with these parameters. Different colors are used for each data series, and line 4 is in red.

When increasing the values for M and N, respectively, it is noted that the "estimation of the time displacement" increasingly depends on β, while for small values of M and N, the error in determining the arrival time of the reflected pulse increases. This is confirmed by graphs 3 and 4, which are displayed for the same values of M and N, (M=7, N =15), but where curve 3 uses β = 0.55, and curve 4 uses β = 0.1.

The smaller the smoothing coefficient, the more the shape of the LPF's amplitude-frequency characteristic (AFC) approaches a "rectangular" shape, which in turn leads to increased accuracy in measuring the arrival time of the USP reflected from the target.

Based on the conducted simulation studies and the comparison of the obtained results with those obtained by the MUSIC method, it can be stated that this method can also determine the complex amplitudes of the individual components. The same applies to the application of Prony's method.

The obtained numerical results, which are not shown in the report, once again confirm the conclusions made earlier in publications dedicated to the topic, that the LPF parameters, the number of required samples (the quantity of reflected USPs in the packet), the S/N ratio, etc., equally affect the accuracy of determining the arrival time of the reflected USP and the accuracy of estimating the USP amplitudes.

4. Results and Discussion.

To demonstrate the performance of the synthesized algorithm with a priori unknown shape of the input USP reflected from the target, an additional assumption in the mathematical expressions describing the operational sequence is the use of a value for $\dot{f}_m = 1$, i.e., independent of the shape of the input signal envelope. The simulations conducted in Matlab did not show significant changes in the previously obtained results for the accuracy of determining the arrival time of the reflected USP and the estimation of the complex amplitudes of the USPs in the packet of reflected signals. With the initial and boundary conditions thus set, an increase in accuracy within 5-6% was noted, which does not lead to significant changes in the values for time delay (distance to the observed object) and the estimation of the complex amplitude of the USP in the packet. That is, for an a priori unknown shape of the reflected USP, in the proposed algorithm, it is necessary to use $\dot{f}_m = 1$, which also proves the algorithm's performance.

5. Conclusion.

An estimation of the allowed error when changing the initial conditions for the algorithm's operation was made, and it was proven that the modified algorithm retains its performance even with an a priori unknown shape of the reflected signal, and in conditions of Gaussian noise influence on the input packet of reflected pulses when using Prony's method – and in this specific case, also when using the MUSIC method.

The report shows that the accuracy of the estimation primarily depends on the smoothing coefficient of the Nyquist LPF, on the choice of parameter M, which determines the resonant frequency of the preliminary LPF, and on parameter N, which, in turn, determines the necessary number of reflected USPs in the packet (samples) formed at the output of the preliminary LPF.

Acknowledgements:

The scientific research, the results of which are presented in this publication, was funded by the Research Sector at the Technical University – Sofia under a project for doctoral student support.

6. References.

1. Radzievsky V. G., Trifonov P. A. Processing of ultrawideband signals and interference. — M. : Radiotekhnika, 2009. — 288 p.29

2. Lazorenko O. F., Chernogor L. F. Ultrawideband signals and physical processes. 1. Basic concepts, models and description methods // Radiophysics and Radioastronomy. — 2008. — V. 13. — № 2. — P. 166—194.

3. Win M. Z., Scholtz R. A. Impulse radio: How it works // IEEE Commun. Lett. 1998. — V. 2. — № 2. — P. 36.

4. Sklyar B. Digital Communication: Theoretical Foundations and Practical Application: trans. from English. — M. : Williams. — 2003. — 1104 p.30

5. Shcherbakov V. S. Correlation-filter method for processing ultrawideband LFM signals // Journal of Radioelectronics.-2018.-№2.

6. Parfenov V. I. Detection and Parameter Estimation of Ultra-Short Pulse based on the Compressive Sensing Theory // Compressive Sensing: Methods and Applications / edited by R. Matthews. — 2000. — P. 61—94.

7. Parfenov V. I., Golovanov D. Y., Kunaeva N. A. Algorithms of signal parameter estimation based on the theory of Compressive Sensing and their computer simulation // Journal of Physics. Conference Series. — 2019. — V. 1479.

8. Proakis D. Digital Communication / trans. from English; edited by D. D. Klovsky. — M. : Radio and Communications, 2000. — 800 p.

9. Parfenov V. I., Golovanov D. Yu. Noise immunity of signal reception algorithms with multi-pulse position-pulse modulation // Computer Optics. — 2018. — V. 42. — № 1. — P. 167—174.

10. Stoica P., Moses R. Introduction to Spectral Analysis. — Englewood Cliffs, NJ: Prentice-Hall, 2000.