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Pulse interference detection in measurement systems

***Abstract**. The paper presents an suboptimal algorithm of detection of interference pulses in industrial measurement devices and telecommunication systems which can be used for pulses excision. Performance characteristics of the detection procedure are obtained for interference pulse models with a different probability density functions of amplitude fluctuations.*

***Streszczenie.** W artykule został przedstawiony suboptymalny algorytm detekcji zakłóceń impulsowych w przemysłowych systemach pomiarowych oraz w systemach telekomunikacyjnych który może być wykorzystany do eliminacji impulsów zakłóceń. Przedstawiono wybrane wyniki symulacji zaproponowanego algorytmu. (**Detekcja zakłóceń impulsowych w systemach pomiarowych**).*

Keywords: Pulse, reliable data processing, electromagnetic compatibility.
Słowa kluczowe: Zakłócenia impulsowe, niezawodne przetwarzanie danych, kompatybilność elektromagnetyczna

Introduction

In industrial measurement devices, telecommunication and automatic control systems observed data are often corrupted by pulse interferences originated from different sources such as atmospheric noise bursts, radio noise from lightning discharges, industrial and vehicular pulse interferences and some others [1, 2]. The presence of pulse interferences results in an appearance of outliers at the output of a measurement device.

There are two possible approaches to eliminate the influence of the pulse interference upon the final result of the measurement process. The first one consists in detection, parameter and waveform estimation of pulse interferences and the subsequent subtraction of the estimated signal from the input signal. In this case the measurement process is not subjected to the effect of the pulse interferences. In the second approach the pulse interferences are permitted to apply to the measurement device and elimination of the outlier aftereffects is carried out by a proper design of a signal processing algorithm [3]. In this paper we consider the first approach. The design of the robust with respect to the pulse interference signal processing algorithm was presented in [4].

Problem formulation

The transmitted signal is a non-linear function of the information data stream $x(t)$ and depends on the modulation type h[t*:x(t*]:

(1) $$S_t(t) = h[t, x(t)]$$

A model of the data stream *x(t)* is usually described by the linear state equation of the following form

$$\dot{x}(t) = F(t)\,x(t) + G(t)w(t),$$

where *x(t)* is the state vector, *F(t)*-the system matrix and *G(t)* is the input matrix of the forming filter.

The received signal *r(t)* at the input of the receiver in the presence of pulse interferences can be written as the following non-linear equation:

(2) $$\begin{aligned} r(t) &= h[t : x(t)] + n(t) + \gamma(t)\,A\,s_o(t-\tau_0) = \\ r(t) &= h^*(t) + \gamma(t)\,A\,s_o(t-\tau_0) \end{aligned}$$

where

(3) $$h^*(t) = h[t : x(t)] + n(t),$$

$h[t : x(t)]$ is a useful signal modulated by a information process *x(t)*, *n(t)* is the white noise at the receiver input with the power spectral density N_0, $\gamma(t)$ is a random binary switching function which can take on values 1 or 0 depending upon the presence or absence of a pulse interference $s_o(t)$, A is the pulse amplitude and τ_0 is it's the true time delay.

The objective of the paper is to determine a structure and performance characteristics of the optimal detection and parameter estimation of the pulse interference $A\,s_o(t-\tau_0)$.

It is worthy to notice that for the problem under consideration the process (3)

$$h^*(t) = h[t : x(t)] + n(t)$$

are considered as an interference.

If the waveform of the pulse interference $s_o(t)$ and its delay τ_0 is not known then the detection and estimation algorithm has to be realized in the multi-channel form.

Detection and estimation algorithms

As it is known [2] the optimal receiver of a pulse interference has to calculate the logarithm of a likelihood ratio $\lambda(r)$ and to compare it with a decision level λ_0. The likelihood ratio depends on the statistical characteristics of the process $h^*t)$ and a signal model. If we deal with a telecommunication system with a bandwidth which is more wider the bandwidth of the pulse interference $s_0(t)$ then the process $h^*t)$ can be considered as a white noise. In opposite case the procedure of noise whitening must be used [2, 5]. In this paper we assume that the process $h^*t)$ is white noise. Besides it is supposed that the interference pulse $s_o(t)$ is a baseband signal.

Then the logarithm of a likelihood ratio (LR) for a known waveform and amplitude of the pulse can be written as follows [5]:

(4) $$\lambda(r \mid A) = \gamma(t)\frac{2A}{N_0}\int_0^T s_0(t-\tau_0)s_0(t-\tau)dt + +\frac{2}{N_\lambda}\int_0^T \lambda^*(t)\,s_0(t-\tau)dt\,,$$

where N_λ is the power spectral density of the white noise process $h^*(t)$, T is the observation interval which is commensurable with the pulse duration.

The first term in (4) is the autocorrelation function $\rho(\xi = \tau - \tau_0)$ of the interference pulse, the second is the output noise with a variance equal to the signal-to-noise ratio (SNR)

(5) $$q = 2E_{so} / N_\lambda$$

where E_{so} is an energy of the pulse.

The autocorrelation functions and energy of typical interference waveforms are presented in Tab. 1.

Table 1. Characteristics of interference pulses

Pulse waveform	Energy E_{S0}	Autocorrelation function $\rho(\xi)$
1) $A\frac{\sin\omega_c t}{\omega_c t}$	$\frac{\pi}{\omega_c}A^2$	$A\frac{\sin\omega_c\xi}{\omega_c\xi}$
2) $A(1-\frac{\lvert t\rvert}{T_{tr}})$	$\frac{2T_{tr}}{3}A^2$	$1-\frac{\xi}{T_{tr}}$
3) $Ae^{-\beta^2 t^2}$	$\frac{\sqrt{\pi}}{\sqrt{2}\beta}A^2$	$\exp\{-\frac{\beta^2\xi^2}{2}\}$
4) $A\exp\{-\beta t\}$	$\frac{1}{\beta}A^2$	$\exp\{-\beta\xi\}$
5) $A\sin^2(\frac{\pi}{T_{so}}t)$	$\frac{3T_{so}}{2}A^2$	$\approx\cos^2\frac{\pi\xi}{T_{so}}$

If an amplitude of the interference pulse is random with a probability density function (pdf) *p(A)* then the LR can be written as follows:

(6) $$\lambda(r)=\int_0^\infty \lambda(r\,|\,A)\,p(A)\,dA\,,$$

In a case of baseband signals the pdf of amplitude fluctuations usually is described by one of the following density functions:

- Gaussian function (GF)

(7) $$p_G(A)=N(0,\sigma_A^2)\,,\ -\infty<A<\infty$$

- bilateral Rayleigh function (BRF)

(8) $$p_R(A)=|A|/2\sigma_A^2\exp\{-2A^2/\sigma_A^2\}\,,\ -\infty<A<\infty$$

- uniform density function (UF)

(9) $$p_U(A)=1/\Delta\,,$$

where σ_A^2 is the variance of the amplitude fluctuations.

The decision level can be chosen using different criteria [2, 5]. In this paper the Neyman-Pearson criterion has been used. For a known value of the interference pulse amplitude the probability of a false alarm can be found as:

(10) $$P_{fa}=\frac{2}{\sqrt{2\pi}}\int_{\lambda_0}^{\infty} e^{-\frac{r^2}{2q}}\,dr\,,$$

because the second term in (4) has a Gaussian distribution with the variance (5). The expression (10) makes it possible to determine the value of the decision level λ_0 and to calculate the detection probabilities P_D for different models of pulse fluctuations on the basis of the pdf (7)-(9).

The performance characteristics of the pulse detection procedure for different fluctuation models are presented in Table 2.

Table 2. Detection probabilities of interference pulses

SNR [dB]	$p_G(A)$		$p_R(A)$		$p_U(A)$	
	P_D		P_D		P_D	
	P=10^{-2}	P=10^{-8}	P=10^{-2}	P=10^{-8}	P=10^{-2}	P=10^{-8}
7.8	0.65	0.30	0.82	0.40	0.75	0.42
10	0.77	0.50	0.93	0.68	0.82	0.62
13	0.88	0.75	0.98	0.91	0.92	0.81

Detection probabilities P_D are calculated for different types of fluctuations (pdf $p_G(A)$, $p_R(A)$, $p_U(A)$) with probability of false alarm $P_{fa}=10^{-2}$ and $P_{fa}=10^{-8}$ and some typical values of the SNR.

As it can be shown from the Table 2 the best detection performance characteristics are obtained for pulses with the Rayleigh fluctuations and the worst for the Gaussian. The detection probability P_D increases with a rise of the variance of amplitude fluctuations σ_A^2. This dependence for the bilateral Rayleigh pdf are shown in Tab. 3.

Table 3. Performance characteristics for different variances σ_A^2

SNR [dB]	$\sigma_A^2=0.25$		$\sigma_A^2=0.5$		$\sigma_A^2=1.0$	
	P_D		P_D		P_D	
	P=10^{-2}	P=10^{-8}	P=10^{-2}	P=10^{-8}	P=10^{-2}	P=10^{-8}
7.8	0.68	0.21	0.82	0.40	0.91	0.61
10	0.84	0.49	0.93	0.68	0.96	0.82
13	0.96	0.82	0.98	0.91	0.99	o.95

After an estimation of the pulse time delay, the detected interference pulses can be subtracted from the data stream for improving the results of data processing. If the pulse waveforms are not known one has to use the bank of algorithms (4) matched with the corresponding waveform and to choose a channel with the maximum value of $\lambda(r\,|\,A)$.

Conclusions

In the paper the problem of interference pulses detection in telecommunication and measurements systems is considered. An information process has been considered as interference. A suboptimal algorithms and performance characteristics of detection procedure are obtained for an interference pulse model with fluctuating amplitude. There were investigated three types of probability density functions: Gaussian, bilateral Rayleigh and uniform. It is shown that detection probability greatly depends on a value of fluctuation variance. The results of interference pulse detection can be used for theirs elimination in the data processing procedure. If the wave forms of the interference are not known the multi-channel procedures must be used. The optimal choice of the waveform can be carried out using maximum likelihood principle.

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