BRIEF COMMUNICATIONS

PRECISION METHOD OF DETERMINING THE TIME DELAY IN MULTICHANNEL SIGNAL PROPAGATION

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One of the important problems arising when processing signals propagating over several channels with various noise characteristics is a determination of their time delay [1]. In the case of two channels formulation of the problem reduces to the following form: We have two signals:

$$s_1(t) = x(t) + \xi(t);\; s_2(t) = x(t - t_0) + \eta(t), \tag{1}$$

where $x(t - t_0)$ is the delayed signal $x(t)$, and $\xi(t)$, $\eta(t)$ are white Gaussian noise uncorrelated with the signal. It is necessary to determine the time delay t_0. The cross-correlation function (CCF) of processes $s_1(t)$ and $s_2(t)$ has the form:

$$R(\tau) = R_x(\tau \pm t_0) + R_{\xi\eta}(\tau), \tag{2}$$

where $R_x(\tau \pm t_0)$ is the correlation function (CF) of the signal $x(t)$, and $R_{\xi\eta}(\tau)$ is the CCF of noise $\xi(t)$ and $\eta(t)$. The global maxima in $R(\tau)$ reflecting the displacement of the processes will be located at points $\tau = \pm t_0$.

The traditional approaches to solving the problem of determining the delay are based either on investigating the correlation data (2) at the extremum [2] (under the condition of smallness of noise) or on an analysis of the spectrum of function (2) [1] (under the condition of smoothness of the spectrum of the signal $x(t)$ and cross spectrum of the noise (t)).

In practice the effect of strong noise can lead to displacement, distortion, and even complete suppression of the principal maximum in CCF (2). Filtering is one of the ways of increasing the accuracy of determining the delay [2]. It is known that when realizing Fourier transformation of signals with a limited spectrum, white noise has the greatest effect on high-frequency Fourier coefficients. Therefore, the following procedure is usually used for suppressing white noise components in the CCF (2).

Step 1. Direct Fourier transformation of each of the signs $x(t)$ and $x(t - t_0)$ is performed.

Step 2. The high-frequency Fourier coefficients in each of the Fourier sequences obtained are cut off.

Step 3. Termwise multiplication of the truncated sequences is carried out.

Step 4. Inverse Fourier transformation of the sample of Fourier coefficients obtained is realized.

Such an approach provides smoothing of the noise components in the estimate of CCF (2), but by virtue of the fundamental limitedness of frequency resolution of the Fourier method, the accuracy of determining the delay t_0 is low [3].

For a precision determination of the time delay with an accuracy higher than that of classical estimation methods, it is suggested to use in step 4, in place of inverse Fourier transformation, the nonlinear method of spectral estimation providing superresolution. A Toeplitz matrix, which is interpreted as a matrix of samples of the correlation function of a certain random field, is formed from the Fourier coefficients remaining after truncation. In such a formulation, realization of inverse Fourier transformation reduces to the classical problem of spectral estimation: on the basis of a finite number of samples of the CF of the stochastic process, construct the estimate of its spectral power density (SPD).

We will apply to the solution of this problem the known principle of maximum information entropy (ME) [4]. It has been shown [3] that the classical ME method in Berg's formulation provides a high resolution and noise immunity, but serious difficulties related to an irregular iteration procedure of constructing the solution arise with its use. It is suggested to calculate the estimate of the SPD on the basis of an expression obtained by means of a variant of using the ME principle differing from the traditional

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