The Filter Design Technique for Trend Change Detection of Random Process in Real Time

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Abstract: A filter for non-stationary processes, which allows receiving real-time filtering result without edge effects and delay, was proposed. Designed filtering algorithm can be used for continuous monitoring of technological processes of production conducted in order to prevent emergency situations and/or output of the process beyond the technological limitations. Built filtration system includes a Kalman filter and optimum discrete filter for random time series with stationary increments.

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Keywords: quality assurance and maintenance, edge effects, parametric model, filtration, Kalman filter

1. INTRODUCTION

The problem of monitoring continuous flow processes within the aim to prevent emergency situations and/or the output of the process beyond the technological limitations is discussed in this paper. In a regular mode the process parameters are subject to random fluctuations, which mask the direction change of the trend. In order to single out the trend the process is filtered in such a way that as the result of the filtrations:

- it would be possible to single out the trends one wants to detect;
- the results of filtering do not contain high frequency oscillations of the increments.

The problem of trend change detection can be posed as that of finding time moments, in which the increment of the filtered process changes sign. There are a lot of filtration methods permitting to single out the low-frequency component of observed processes in a posterior regime and delete the high frequency oscillations of increments involved. However the application of these filtration algorithms in real-time (as the data of the observations arrive) disturb the process. The received results become the source of false conclusions about its properties, and, in particular, lead to a delay in the detection of trend changes.

The real-time filtering algorithm, which allows you to get the result of filtering in the current mode, close to the result obtained in the off-line mode, is proposed in this paper.

2. PROBLEM STATEMENT

2.1 Description of problem statement

Let us consider the technological object, the parameters of which are observed at discrete points in time and are described by the random non-stationary process. If in the process the high-frequency oscillations are absent, then a change in trend is accompanied by a change of sign in an increment series (differentials) of the process. In the presence of high-frequency oscillations in the process the changes in trend is masked by these fluctuations. The standard way to remove high-frequency oscillations is filtering. To detect changes in trend we can filter out the process with use low-pass filters, which allocate such trend changes, which is necessary to detect in a timely manner. The filter must change sign in those (and only those) points of the filtered process in which the changes of the trend occur.

In off-line for a wide range of processes, we can use: linear filters, filters based on singular spectrum analysis, wavelet filtration, and so forth. Solution of the filtration problem in real time is complicated by the presence of edge effects. Under the edge effect we mean fluctuating data at either end of a record after applying a filter. If your record is long enough, you simply discard the first and last several data. But if the process is observed and, consequently, it is filtered in real-time, the distortions introduced by edge effects, reduce the quality of the resulting solutions and/or do not allow to solve the problem.

Figure 1 shows the following graphics: fragment of the process (thin line); the result of filtering in a posterior regime by the low-band filter with the have been discarded edge effects (bold line); the results of filtering by this filter, in real time, at intervals ending at time t (dotted thin lines).

Figure 2 shows plots of the increments of the source and the filtered processes, presented in Figure 1.

Let us formulate statement of the problem: for a given the filter constructed on the training sample in off-line, it is necessary to construct the real time filter with the same characteristics.

Quality of the real-time filter will be evaluating by the following characteristics:

- sum of absolute differences of the process values at the beginning and the end of the observed trend, multiplied by the sign of the increment of the filter at the moment of changes detection;
• the number of detections of the changes of trend.

These characteristics are compared with the characteristics of the low-band filter which is constructed in the same range (taking into account of boundary effects) in off-line.

Fig. 1. Technological process, __ the result of filtering off-line, — real-time filtration, - - - .

Fig. 2. The process increments, __ , increments of the filtered off-line, — , increments of the filtered in real time, - - - .

2.2 Specific problem statement

We consider non-stationary random process with stationary increments of the first order. Process \( X = \{ x_1, x_2, \ldots, x_i, \ldots \} \) is called a process with stationary increments of the first order, if sequence of differences \( \Delta x_i = x_i - \Delta x_{i-1} \), \( i = 2, 3, \ldots \) is a stationary process. With use a training sample of observations of the process parameters:

\[
x_1, x_2, \ldots, x_i, \ldots, x_{t_1}, x_{t_2}, \ldots, x_N,
\]

we built a filtered signal

\[
Y = \{ y_{t_1}, y_{t_1+1}, \ldots, y_{t_2} \},
\]

which it is considered in the interval, \( [t_1, t_2] = [t_1, t_1 + 1, \ldots, t_1 + L - 1 = t_2] \), where \( L = t_2 - t_1 + 1 \) – length of the interval, \( 1 < t_1, t_2 < N \). The results of filtering in the ends of the intervals have been discarded, to avoid the edge effects. We were evaluating the filtering quality by precision of the trend changes determine of the signal (1). Let \( t_1 + 1, t_1 + 2, \ldots, t_1 + k \), where \( t_1 < t_1 + 1 < t_1 + 2 < \ldots < t_1 + k \leq t_2 \) – the sequence of time moments, where the first-order increments of the filtered signal (2), \( \Delta_{t_1+1}, \Delta_{t_1+2}, \ldots, \Delta_{t_1+k} \), change the sign, and \( \Delta_{t_1+i} = y_{t_1+i} - y_{t_1} \), \( \Delta_{t_1+i+1} = y_{t_1+i+1} - y_{t_1+i} \), \( i = 2, 3, \ldots, k \), then the quality of the constructed filter is estimated as:

\[
B = \sum_{j=1}^{k} (x_{t_1+j} - x_{t_1+j-1}) \text{sign} (\Delta y_{t_1+j}),
\]

representing the sum of products of process differences (1) at the endpoints of intervals, \( [t_1, t_1 + 1], [t_1 + 1, t_1 + 2], \ldots, [t_1 + k - 1, t_1 + k] \), by the sign of increments \( \Delta_{t_1+1}, \Delta_{t_1+2}, \ldots, \Delta_{t_1+k} \), where \( k \) – the number of detected changes. Needed is to design the filter for definition of the trend changes in current mode, that its characteristics \( B, k \) satisfy the conditions:

\[
\begin{align*}
U1. & \quad B' \geq 0, \quad BR = 100\% \frac{B - B'}{B} < 15\%, \\
U2. & \quad kr = 100\% \frac{k - k'}{k} < 15\%,
\end{align*}
\]

where \( B, k \) were calculated for the filter with the desired characteristics. This filter has been built in the offline mode. The first condition restricts the reduction in the accuracy of determining the trend, the second - restriction in the frequency of detections.

3. REAL TIME FILTERING ALGORITHM

3.1 Restrictions definition

In the specific problem statement the only limitation is indicated: the process must have the stationary increments of the first order. In such way both stationary and non-stationary processes may be considered. The type of the filter, which desired signal can be built, is unrestricted. Additional restrictions are necessary for design of the filtration algorithm in real time.

Restriction 1. Filtered signal with the desired characteristics may be described by one of the parametric equation types (AR, MA, ARMA, ARIMA) with normal distribution of the residuals.

Restriction 2. The values of the observed process can be described as the sum of a linear combination of the values of the filtered desired signal and noise with normal distribution. If the observed process does not satisfy this condition, then it must be filtered preliminarily by the filter which has been suggested in the paper of Gelfand and Khmelnik (2008).

If the both restrictions are carried out, the filtration in real time may be performed with used the Kalman filter (Hamilton, 1994).
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