Управління в складних системах

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RELATIONSHIPS BETWEEN FILTER-EXTRAPOLATOR PARAMETERS AND QUALITY OF FILTRATION AND FORECAST

Introduction. In the article I analyzed the relationships between parameters of the adaptive exponential smoothing filter and quality of filtration and forecast. Adaptation principle of the exponential filter is based on use of the method of least squares. **Aims.** To analyze the quality of the algorithm's adaptation and define the conditions in which it can work appropriately. To get the information that describes connection between data processing parameters and quality of filtration and forecast. **Methodology.** I have applied concepts of time series analysis and mathematical simulation in Matlab package. **Results.** I have obtained approximate values of different parameters that describe conditions of the system or device in which this filtering and forecasting algorithm can be integrated. I assessed the quality of smoothing factor adaptation method establishing relationships between parameters. **Originality**. For the first time I have defined the relationships between rms-errors (filtration and forecast) and the following parameters: the number of steps which the forecast is made for, the quantity of steps which the data processing algorithm uses for quality estimation of filtering process, the value that defines acceptable error and smoothing factor initial value. I also got the information that describes the connection between some of the tparameters mentioned above. **Practical value.** I have built a structure of the data processing algorithm that can be integrated into different automated control systems. This research gives an opportunity to choose appropriate parameters of the filtering and forecasting algorithm that will give an ability to filter and make a prediction of a signal in channels of measurement and control channels. Proposed data processing algorithm can be implemented as a program for a microcontroller.

Keywords: data processing algorithm, exponential smoothing, noise, forecast, original signal, adaptation, smoothing factor.

Introduction

The task of the automated control system parameters optimization, as a rule, depends on the accuracy of the data obtained from the measuring devices, as well as the quality of control signals. Many automated control systems can not function without data processing algorithms such as filtration and prediction of the original signal.

The quality of filtration and prediction, as well as speed of the control process, depends on the parameters that determine the degree of the signal smoothing, the time which the forecast is made for and others. Sometimes the elements of the system, in which the filtering algorithm is integrated, are exposed to distortions that are not stationary. That is why the data processing algorithm must include the adaptation of the filter parameters.

Algorithms of adaptation operate with different speed due to the fact that data accuracy which is needed to estimate the quality of filtering process can be different and the resources that are necessary to implement data processing algorithm into computing machines are different as well.

This paper is the first one where I tried to conduct a comparative analysis of the exponential filter which adaptation process is based on use of the method of least squares [1], filter with two loops previously presented in [2] and the filter with three loops described in [3], trying to establish a relationship between the change in filter parameters and the magnitude of prediction and smoothing errors.

In this article I focused attention on the exponential smoothing filter whose adaptation algorithms is based on use of the method of least squares [1].

Formulation of the problem

There is a double exponential smoothing in the basis of all three filters structures, which can be conditionally called the simplest filtering element. The combination of these elements and connections between them form the main filtering structure which principle was previously presented in [4].

Each structure of the adaptation algorithm can be extended. It is well known that complex structure demands more resources than simple. That is why proposed algorithms should be analysed to get information about conditions and automated control systems in which data processing algorithms can be integrated before trying to make them more complex.

Different types of measuring and controlling devices can also impose limitations on data processing algorithm. In this case it is important to define the range of parameter values and their combinations that can give satisfactory results.

There are two main parameters which can influence on the quality of filtration and forecast excluding smoothing factor. They are the number of steps which the forecast is made for and the number of steps which the data processing algorithm uses for quality estimation of the filtering process. If we are talking about a filter which adaptation algorithms are based on use of the method of least squares there are two more parameters that can significantly affect the quality of forecast and filtration. They are the value that defines acceptable error and the initial value of smoothing factor. The first of them is important because it is a key parameter in this method of adaptation and the second one is needed to be researched since this method of adaptation does not provide increase of smoothing factor.

Adaptation of the filter using the method of least squares

The algorithm of the filter's parameters adaptation based on the method of least squares working principle extend description was represented before [1]. Briefly I can present working principle with flowchart shown in the figure 1.

Filtering parameters are:

α – smoothing factor;

α_0 – smoothing factor initial value;

m – the quantity of steps which the forecast is made for;

e_t – the quantity of steps which the data processing algorithm uses for quality estimation of filtering process;

$\Delta\alpha$ – the value of smoothing factor change after estimation process;

e_{acc} – the value that defines acceptable error;

x(k) – the value of input signal;

x(k)* – original signal;

N(k) – noise or distortion;

n – the quantity of measurements;

t – the counter that checks whether the data array for estimation is filled;

$x_{pred}(k+m)$, $x_{filt}(k)$ – predicted and filtered signal value;

$x_{pred}[e\_t]$ – data array of predicted signal;

x_lms(k) – the function that describes the approximated signal got with *polyfit* Matlab function on the basis of array $x_{pred}[e\_t]$;

e_{rms} – root-mean-square error between values of the predicted signal and values of approximated signal.

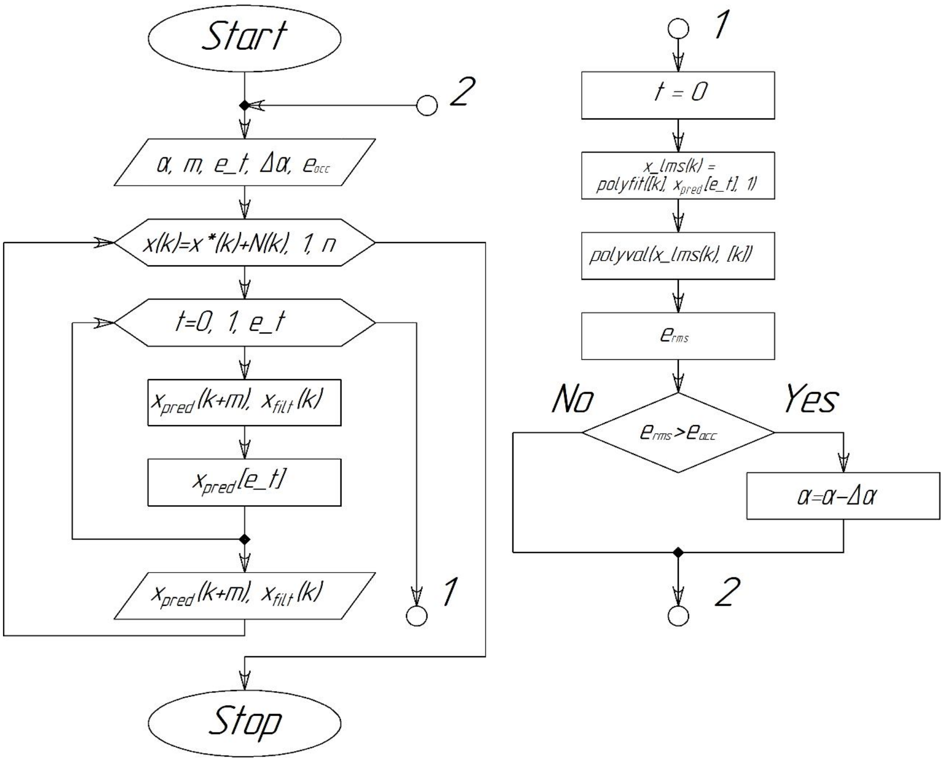


Fig. 1. Adaptation of the filter using the method of least squares flowchart

Relationships between rms-errors and filter parameters

As an input signal I used a sinusoidal wave signal distorted with white noise which standard deviation parameter is changing during the process.

The change of the standard deviation and the shape of the input and tracking signals are shown in the fig. 2.

The period of the sinusoidal wave signal is equal to 720 points and the amplitude value of the tracking signal is equal to 1.

I chose this signal because it includes both linear and nonlinear shapes.

For the quality estimation of filtration and forecast in this research I used two quantities. The first of them is the root-mean-square deviation (rms-error) between the original signal and filtered signal and the second is root-mean-square deviation between values of predicted delayed signal and original signal. The first relationship I researched was between rms-errors (filtration and forecast) and the smoothing factor initial value and the value of steps which the data processing algorithm uses for quality estimation of the filtering process.

First of all, I decided to research the case when the smoothing factor adaptation starts with different values of initial smoothing factor. Since the value of α can vary in a range of 0-1 I chose a range between 0.1 and 0.9.

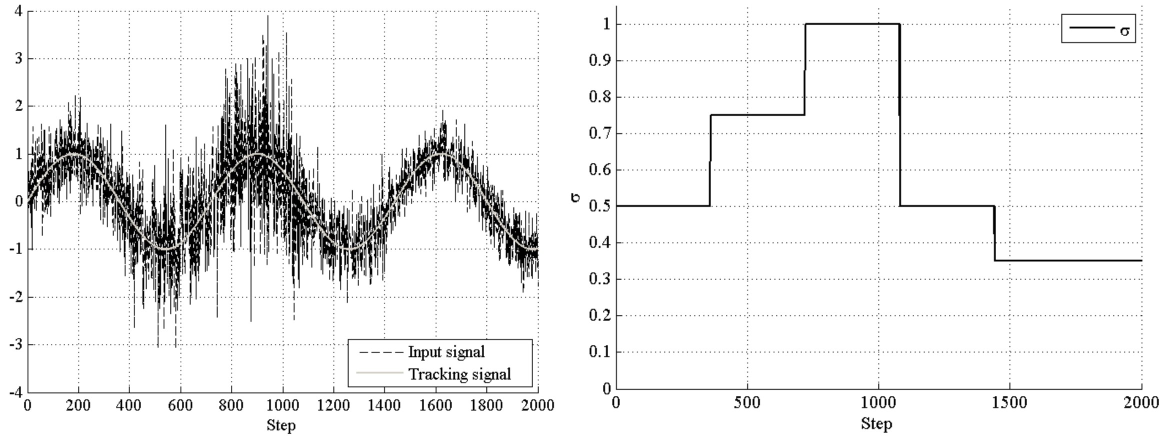
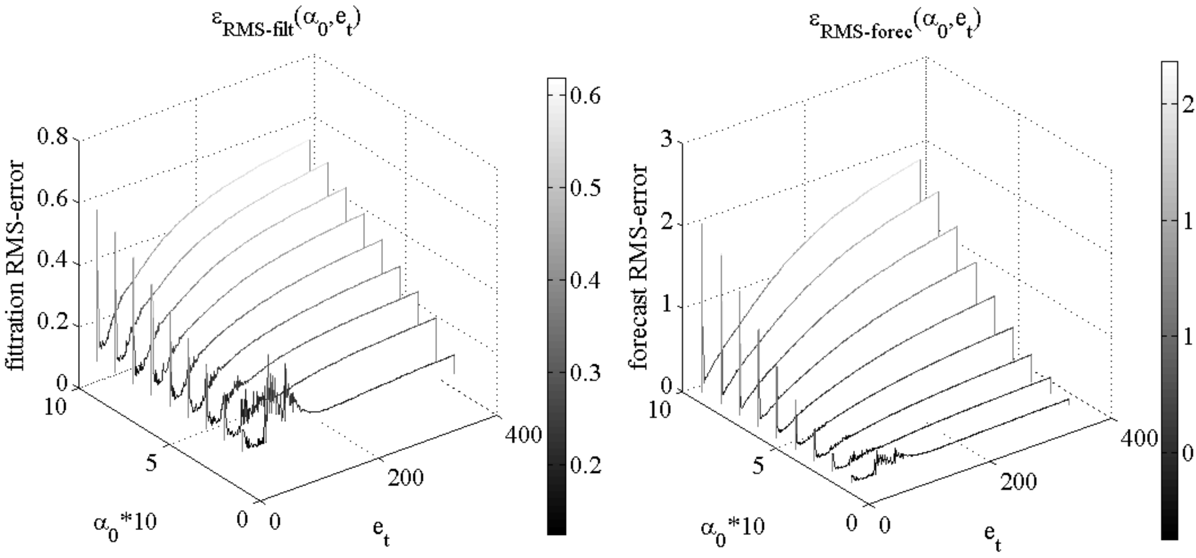


Fig. 2. Input and tracking signal (left plot), values of the standard deviation (right plot)

In this case the value of prediction steps is equal to 2. It means that in such conditions the data processing algorithm works as a filter. The results of the simulation are shown in the fig. 3.


$\varepsilon_{RMS\text{-}filt}(\alpha_0, e_t)$

$\varepsilon_{RMS\text{-}forec}(\alpha_0, e_t)$

Fig. 3. Plots of the rms-errors (filtration and forecast) versus smoothing factor initial value and value of steps which the data processing algorithm uses for quality estimation of the filtering process

Analyzing graphics got after the simulation I made the following statements:

- Using low values of *e_t* (1,2,3) does not give information about the quality of the filtering process and it is unacceptable because of the high values of rms-errors.

- When data processing algorithm starts adapting to the distortion level from the high initial value of smoothing factor, increasing of the *e_t* value leads to increase of rms-errors. Using such composition of values is appropriate when there is lack of information that describes level of noise or distortion.

- Comparing different curves shown in the fig. 3 I defined that the least errors are available when *e_t* values lie in the range between small values that were described in the first statement and values use that lead to errors values fluctuations. In conclusion, the values of *e_t* that give the least values of rms-errors lie in a range between 10 and 20 approximately for such conditions when the original signal is a sinusoidal wave with a period that is equal to 720 and with noise which amplitude value is changing during the process.

In the second research I tried to define the relationship between the rms-errors (filtration and forecast) and smoothing factor initial value and the value that defines acceptable error. The range of α_0 was the same as in the first research. The acceptable error values lay within the range from 0.01 to 1. The results of the simulation are shown in the fig. 4.

Analyzing the graphics shown in the fig. 4 I defined the following statements:

- In the case when we set a low value of acceptable error and low initial smoothing factor value, data processing algorithm inertia grows. This leads to the lag growth and error growth as well. That is why the combination of these two low values is unacceptable.

- The value that defines acceptable error is one of the main parameters that define the quality of filtration and forecast. It is clearly demonstrated in fig. 4. The growth of e_{acc} leads to the decrease of the accuracy

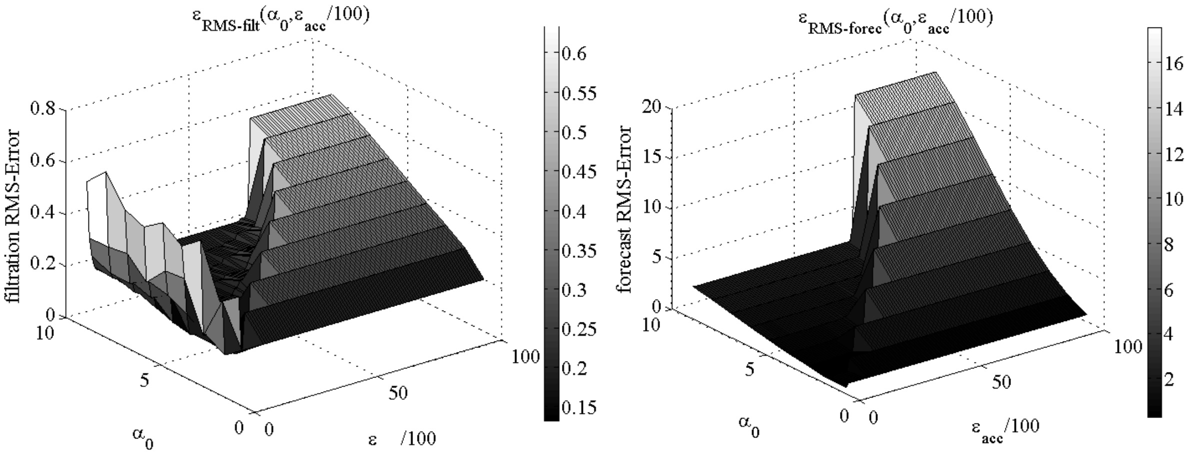


Fig. 4. Plots of the rms-errors (filtration and forecast) versus smoothing factor initial value and value that defines acceptable error

requirements. Acceptable error high values especially decrease the quality of prediction.

- Smoothing factor initial value change has insignificant influence on the relationship between the rms-errors (filtration and forecast) and smoothing factor initial value and the value that defines acceptable error and does not change the shape of the plots in general.

Summarizing statements above, the quality of filtration and forecast generally depends on the acceptable error that is why relationships between this parameter and others are important to be researched.

That is why a few next experiments I performed trying to define relationships between acceptable error and other parameters. The first one was the relationship between rms-errors (filtration and forecast) versus the quantity of steps which the forecast is made for and value that defines acceptable error.

The plots got from the experiment with a parameter *e_t* which is equal to 80. At first, I chose the value equal to 20 according to the fig. 3 because it was in the range of the smallest values of rms-errors. Due to the fact that the first experiment which results are shown in the fig. 3 was performed with *m* parameters equal to 2 I performed this experiment with values of *e_t* [16, 20, 35, 40, 50, 60, 70, 80, 90 ,100, 200].

Most of experiments were performed with $\alpha_0 = 0.1$.

According to the collected data I determined the following statements:

- Setting values of *e_t* parameter lower than 16 leads to a stable value of filtration rms-error which value is about 0.2. The value of forecast rms-error grows according to increase of *m* parameter.

- After increasing *e_t* value to 50 I noticed a tendency that in a case when e_{acc} lies in a range of low values (about 0.01) due to the fact that data processing algorithm becomes more inertial the value of filtration rms-error sharply grows up.

- The field of decreased values of filtration and forecast rms-errors appears as it shown in the fig. 5 in the range of *e_t* values from about 15 to 100.

Using these values in accordance with parameters *m* and e_{acc} will give an opportunity to improve the quality of filtration and forecast.

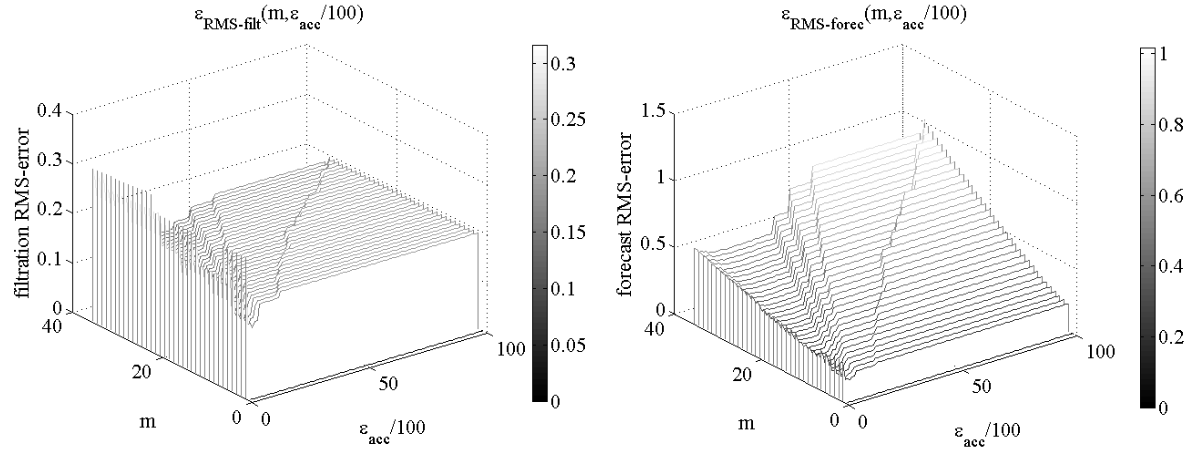


Fig. 5. Plots of the rms-errors (filtration and forecast) versus the quantity of steps which the forecast is made for and value that defines acceptable error

- Increasing *e_t* values to 16-90 increases the decreased values of filtration and forecast rms-errors area but further increase of the value of *e_t* will increase the average values of errors.

- Increasing α_0 leads to limitation of the field of decreased values that depends on *m* parameter. Change of *e_t* parameter influences on errors values as it was mentioned in previous statement.

It is important to note that values of *e_t* that will give an opportunity to get the least values of filtration and forecast errors first of all depend on the shape of the signal and in this article this connection was not investigated.

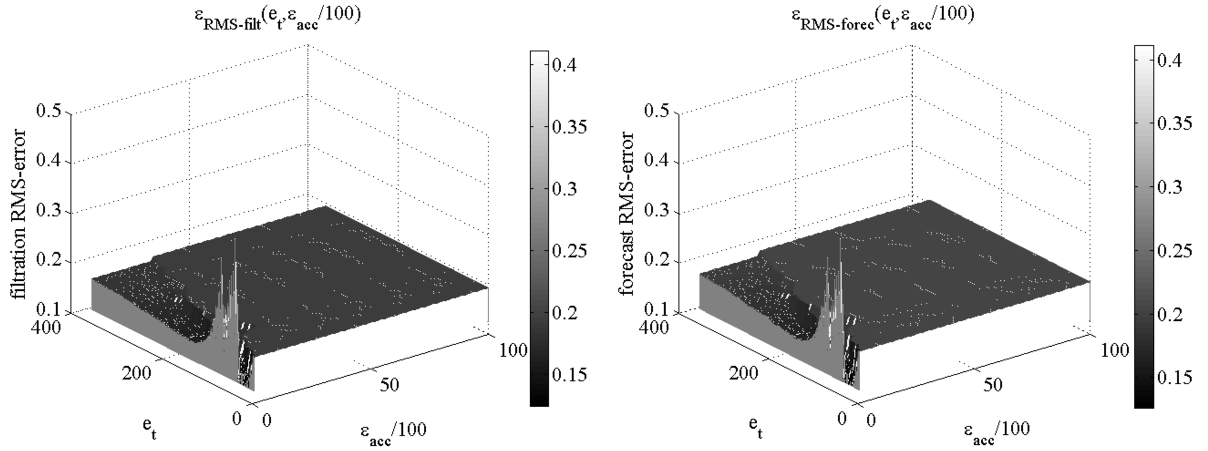


Fig. 6. Plots of the rms-errors (filtration and forecast) versus the quantity of steps which the data processing algorithm uses for quality estimation of filtering process and the value that defines acceptable error

The experiment that is shown in the figure 6 was performed with the following values of parameters: $\alpha_0 = 0.1$, m = 2. Analyzing the plots of the rms-errors (filtration and forecast) versus the quantity of steps which the data processing algorithm uses for quality estimation of filtering process and the value that defines acceptable error I defined following statements:

- These graphics combine peculiar properties of the experiments results that were shown in the fig. 3 and 5.

- Increasing the value of *m* parameter will not change the shape of the surface (fig.6) much but the average value of rms-errors (filtration and forecast) will be higher.

- I tend to think that the relationship between these parameters does not give additional information and can be not taken into account during the setting parameters process.

Analyzing plots of the rms-errors (filtration and forecast) versus the quantity of steps which the forecast is made for and the quantity of steps which the data processing algorithm uses for quality estimation of filtering process I made the following statements:

- Comparing plots shown in the 7th figure and plots in the figure 3 I determined that fluctuations on the plots begin from the value of *e_t* that is equal to 50 and approximately and on the point that is about 100.

- The least values of the rms-errors are available in the case when the parameter *m* is varying between 2 and 10 approximately and *e_t* parameter is varying between 4 and 50 approximately.

- Proposed data processing algorithm can be used as a filter in a case when a value of *e_t* is higher than 100 but it is impractical to use it to get a forecast of the tracking signal.

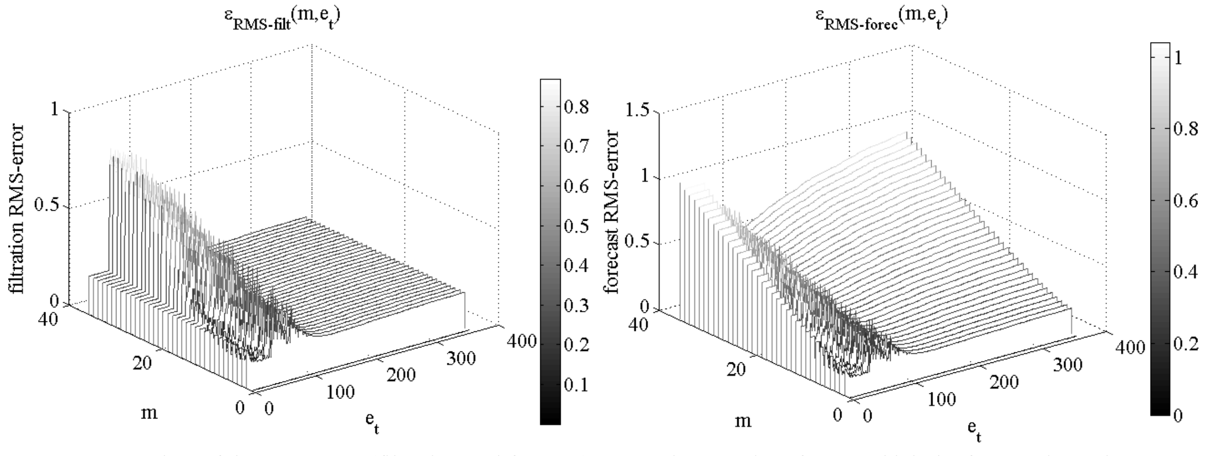


Fig. 7. Plots of the rms-errors (filtration and forecast) versus the quantity of steps which the forecast is made for and the quantity of steps which the data processing algorithm uses for quality estimation of filtering process

Conclusions

Statements that described specific connection between filter-extrapolator parameters and quality of filtration and forecast were presented above. Moreover, the performed research gives an opportunity to define some general conclusions:

- Proposed structure of the filter-extrapolator is able to process data defining tracking signal and its forecast with rms-errors (filtration and forecast) as it was mentioned above.

- The statement that the quality of filtration and forecast depends on before-mentioned 4 parameters was confirmed by experiments.

- Some combinations of different parameters give an opportunity to use this algorithm in a case when there is a lack of a priori information that describes working conditions of the system.

- The shape of the tracking signal plays the most important role in the setting parameters of the filter and should be additionally researched.

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Взаємозв'язок між параметрами фільтра екстраполятора та якістю фільтрації та прогнозу

Б. Р. Боряк

Вступ. У статті розглянуто взаємозв'язок між параметрами адаптивного експоненціального фільтра та якістю фільтрації та прогнозування. Принцип адаптації експоненціального фільтра заснований на використанні методу найменших квадратів. **Цілі**. Проаналізувати якість адаптації алгоритму та визначити умови, в яких він може працювати належним чином. Отримати інформацію, яка описує зв'язок між параметрами обробки даних та якістю фільтрації та прогнозування. **Методологія.** Я застосував концепції аналізу часових рядів та математичне моделювання в пакеті Matlab. **Результати.** Я отримав значення параметрів, які визначають умови системи або пристрою, в яких можна інтегрувати цей алгоритм фільтрації та прогнозування. Я здійснив оцінювання якості адаптації коефіцієнта згладжування, встановлюючи взаємозв'язки між параметрами фільтра. **Оригінальність.** Вперше я визначив зв'язок між середньоквадратичними похибками (фільтрації та прогнозу) та наступними параметрами: кількість кроків, на які здійснюється прогнозування; кількість кроків, які алгоритм обробки даних використовує для оцінки якості процесу фільтрації; значення, яке визначає прийнятну похибку та початкове значення коефіцієнта згладжування. Я отримав інформацію, яка описує взаємозв'язок власне між параметрами, згаданими вище. **Практичне значення.** Я побудував структуру алгоритму обробки даних, який можна інтегрувати в різні автоматизовані системи управління. Це дослідження дає можливість вибрати відповідні параметри алгоритму фільтрації та прогнозування, що дасть можливість фільтрувати та робити прогнозування сигналу в каналах вимірювання та каналах керування. Запропонований алгоритм обробки даних може бути реалізований як програма для мікроконтролера.

Ключові слова: алгоритм обробки даних, експоненціальне згладжування, шум, прогноз, корисний сигнал, адаптація, коефіцієнт фільтрації.

Взаимосвязь между параметрами фильтра экстраполятора и качеством фильтрации и прогнозирования

Б. Р. Боряк

Введение. В статье рассмотрена взаимосвязь между параметрами адаптивного экспоненциального фильтра и качеством фильтрации и прогнозирования. Принцип адаптации экспоненциального фильтра основан на использовании метода наименьших квадратов. **Цели.** Проанализировать качество адаптации алгоритма и определить условия, в которых он может работать. Получить информацию, которая описывает связь между параметрами обработки данных и качеством фильтрации и прогнозирования. **Методология.** Я применил концепции анализа временных рядов и математическое моделирование в пакете Matlab. **Результаты.** Я получил значения параметров, которые определяют условия системы или устройства, в которые можно интегрировать этот алгоритм фильтрации и прогнозирования. Я совершил оценивания качества адаптации коэффициента сглаживания, устанавливая взаимосвязи между параметрами фильтра. **Оригинальность.** Впервые я определил связь между среднеквадратичными погрешностями (фильтрации и прогноза) и следующими параметрами: количество шагов, на которые осуществляется прогнозирование; количество шагов, которые алгоритм обработки данных использует для оценки качества процесса фильтрации; значение, которое определяет приемлемую погрешность и начальное значение коэффициента сглаживания. Я получил информацию, которая описывает взаимосвязь непосредственно между параметрами, указанными выше. **Практическое значение.** Я построил структуру алгоритма обработки данных, который можно интегрировать в различные автоматизированные системы управления. Это исследование дает возможность выбрать соответствующие параметры алгоритма фильтрации и прогнозирования, что позволит фильтровать и делать прогнозирования сигнала в каналах измерения и каналах управления. Предложенный алгоритм обработки данных может быть реализован как программа для микроконтроллера.

Ключевые слова: алгоритм обработки информации, экспоненциальное сглаживание, шум, прогноз, полезный (искомый) сигнал, коэффициент фильтрации.