ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 6, Issue 3, March 2019

Forecasting Non-Stationary Discrete Systems with Limitations on Condition and Management

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ABSTRACT: The article deals with the modeling of non-stationary discrete systems using examples of economic processes that are implemented in time constraints and delays. The purpose of the study is to build monitoring systems that implement the functions of control of reliability, smoothing, regulation of factors leading to the failure to meet the assigned volumes and deadlines. The results of experimental analysis on specific numerical examples. Non-stationary processes reflecting technological, economic, social, biological, physical phenomena are characterized by quantitative and qualitative characteristics, which are inherent by intermittent, evolving growth and regulation of parameters over time. The most suitable mechanism for describing such processes during formalization are dynamic random time series, that allow the use of develop methods and algorithms for regulating descriptive parameters.

KEY WORDS: non-stationary economic process, extrapolator, control, feedback, approximation, statistical prediction, observations, standard deviation, management.

I.INTRODUCTION

It is known that the use of traditional approaches to the synthesis of closed-loop control with constraints leads to a problem called Bellman's "curse of dimension" [6], which significantly complicates the numerical solution of the problem. In this regard, various approaches to taking into account constraints in dynamic models, such as the inclusion of penalties for violating restrictions in the quality criterion [1,3]; building a local-optimal control [4], in which at the control location that is optimal in global terms of thought, the control is determined for the local criterion, for which the consideration of constraints is simplified.

Proceeding from theoretical positions and analytical results of known works, the model of non-stationary discrete system under conditions of constraints and delays is proposed. Conditions for the existence and explicit form of scalar control for a non-stationary system are determined [3]. In view of non-stationarity of investigated processes, and consequently the ambiguity of equations solutions determining the spectrum of transformation matrix of system under conditions of constraints and delays, the task of optimizing control due to analysis, prediction and regulation of perturbing factors parameters is posed. As an estimate of forecast accuracy authors suggested the standard deviation of predicted value by help of which it is possible to calculate the confidence intervals of forecast, since the proposed method of adaptive statistical prediction on the basis of exponential smoothing leaves unresolved the questions of choice of predictive function. The reason for this is that in general case the parabolic model is more efficient than the linear one, however, when variation of the variable time series is stepwise the parabolic model reaches a new level over a longer time interval than the linear one.

According to the proposed method, an algorithm is developed and implemented as a module for approximating and predicting time series. The computational data for three groups of sample data representing stationary periodic (cost of production for example as the production of fruits and vegetables conserves at the enterprises of the Samarkand region, in thousand sums), non-stationary non-periodic (average weighted yield of exchange bonds of the Samarkand region for 2016, in % for year) and non-stationary periodic (the sums of receipts of contract payment to the current account of Samarkand State University, million sum) processes. To optimize the solution of problems when information is incomplete, noisy, distorted, and when it is practically impossible to obtain acceptable solutions using statistical methods of analytical equalization, a study on the use of models of forecasting was carried out.

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II. PROBLEM STATEMENT FOR NON-STATIONARY SYSTEM

As mentioned in the introduction, one of the modern formalized approaches to the synthesis of control of dynamic objects is the controlusing predictive models, the main advantage of which is the ability to manage complex technological processes under severe constraints. Let the model of non-stationary object, channel of observations and controlled output is described by the following relations:

$$\begin{cases} x_{t+1} = A_t x_t + B_t u_t + w_t \\ x_{t|t=0} = x_0 \end{cases} \quad (1)$$

$$\psi_t = H_t x_t + v_t \quad (2)$$

$$y_t = G_t x_t \quad (3)$$

where $x_t \in R^n$ is the state of the object, and, $u_t \in R^m$ is the controlling action (known input), $\psi_t \in R^l$ are the observations, the output of the monitoring system, $x_t \in R^n$ is the controlled output, A_i, B_i, H_i, G_i - matrices of the corresponding dimensions.

It is important to take into account the limitations on the control and the state of the object. Neglect of them can lead to undesirable results, including unstable, oscillatory behavior. Limitations are presented in the form of the following inequalities:

$$a_1(t) \le S_1 x_1 \le a_2(t) \quad (4)$$

$$\varphi_1(x_t, t) \le S_2 u_t \le \varphi_2(x_t, t) \quad (5)$$

where S_1 and S_2 are full-rank structural matrices consisting of zeros and ones, defining the components of the vectors x_t and u_t, which are subject to restrictions; $a_1(t), a_2(t), \varphi_1(x_t, t), \varphi_2(x_t, t)$ are given vectors and vector functions of the corresponding dimensions.

In some tasks it may be that structural matrices may also depend on *t*. Note that in the work on the synthesis of predictive control, the lower and upper limits of the control constraints are usually given by functions that depend only on time. In this paper, such a restriction is removed, and examples are given in which the problem is solved for constraints in which the upper and lower bounds depend on the components state vector. In addition, it is assumed that the pair of matrices A_t B_t is controllable, and the pair of matrices A_t , H_t is completely observable.

Model (1) - (3) is used to predict the behavior of an object for a certain period, which is called the forecast horizon and is denoted by N, using information about the control and, and the observation vector ψ_t , u_t to the current time point t.The task is to determine from observations ψ_t the control strategy, in which the output vector of the system y_t , will be close to the given vector $\bar{y}_t$, taking into account the constraints (4) - (5).

III. BUILD A PREDICTIVE MODEL FOR NON-STATIONARY SYSTEM

Since random perturbations w_t, and measurement noise v_t, have a Gaussian distribution, it is possible to perform an optimal prediction of the object's behavior and the output vector using the Kalman extrapolator [6,7]. Let $\hat{x}_{i|j}$ and $\hat{y}_{i|j}$ - assessments of the state and the output vector at the moment of time i, giving information of the su-th instant of time, $j \le i$. Then

$$\hat{x}_{t+1|t} = A_t \hat{x}_{t|t-1} + B_t u_t + K_t(\psi_t - H_t \hat{x}_{t|t-1}), \hat{x}_{0|-1} = \overline{x_0}, \quad (6)$$

$$\hat{y}_{t+1|t} = G_t \hat{x}_{t+1|t}, \quad (7)$$

$$K_t = A_t B_t H_t^T (H_t P_t H_t^T + V_t)^{-1}, \quad (8)$$

$$P_{t+1} = W_t + A_t P_t A_t^T - A_t P_t H_t^T (H_t P_t H_t^T + V_t)^{-1} H_t P_t A_t^T, P_0 = P_{x_0}, \quad (9)$$

ISSN: 2350-0328
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The equation for P_t, (9) is known as the discrete-time Riccati difference equation, P_{x_0} is the initial value of the dispersion matrix. To implement the predictive control model, you must have the ability to calculate estimates of the state vector at time points *t+1, t+2, ..., t+N*, based on the information available at time t. From equations (6) - (9), you can get $\hat{x}_{t+1|t}$ as well as optimal estimates for moments *t + 2, ..., t + N:*

$$\hat{x}_{t+i-1|t} = A_{t+i}\hat{x}_{t+i|t} + B_{t+1}u_{t+i|t}, \hat{x}_{1|0} = \overline{x_0}, i = \overline{1, N-1} \tag{10}$$

$$\hat{y}_{t+i|t} = G_{t+i}\hat{x}_{t+i|t}, i = \overline{1, N} \tag{11}$$

Here, the designation $u_{t+i|t}$, is used to distinguish the current control at the moment $t + i\,u_{t+i|t}$ from those used for the purpose of prediction - $u_{t+i|t}$.

Controls used for the purpose predictions are searched for on the control horizon M, and the prediction of the state of the object is carried out over a larger interval N (M <N). To calculate $\hat{x}_{t+M+2|t},\ldots,\hat{x}_{t+N|t}$ in (10) as $u_{t+M+1|t},\ldots,u_{t+N-1|t}$ and $u_{t+M|t}$ is used, assuming that management is kept at that level.

Constraints (4) - (5) can also be transformed to vector-matrix constraints for the predictive model:

$$\begin{bmatrix} a_1(t+1) \\ \vdots \\ a_1(t+N) \end{bmatrix} \le \begin{bmatrix} S_1\hat{x}_{t+1|t} \\ \vdots \\ S_1\hat{x}_{t+N|t} \end{bmatrix} \le \begin{bmatrix} a_2(t+1) \\ \vdots \\ a_2(t+N) \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} \varphi_1(\hat{x}_{t+1|t}, t+1) \\ \vdots \\ \varphi_1(\hat{x}_{t+M|t}, t+M) \end{bmatrix} \le \begin{bmatrix} S_2u_{t+1|t} \\ \vdots \\ S_2u_{t+M|t} \end{bmatrix} \le \begin{bmatrix} \varphi_2(\hat{x}_{t+1|t}, t+1) \\ \vdots \\ \varphi_2(\hat{x}_{t+M|t}, t+M) \end{bmatrix}, \tag{13}$$

We introduce the notation:

$$\overline{a}_1(t) = \begin{bmatrix} a_1(t+1) \\ \vdots \\ a_1(t+N) \end{bmatrix}, \quad \overline{a}_2(t) = \begin{bmatrix} a_2(t+1) \\ \vdots \\ a_2(t+N) \end{bmatrix}$$

$$\overline{S}_1 = diag(\underbrace{S_1,\ldots,S_1}_{N}) \quad \overline{S}_2 = diag(\underbrace{S_2,\ldots,S_2}_{M}) \tag{14}$$

$$\overline{\varphi}_1(\overline{X}_t, t) = \begin{bmatrix} \varphi_1(\hat{x}_{t+1|t}, t+1) \\ \vdots \\ \varphi_1(\hat{x}_{t+M|t}, t+M) \end{bmatrix}, \overline{\varphi}_2(\overline{X}_t, t) = \begin{bmatrix} \varphi_2(\hat{x}_{t+1|t}, t+1) \\ \vdots \\ \varphi_2(\hat{x}_{t+M|t}, t+M) \end{bmatrix}$$

Then the constraints (12) - (13) for the predictive model are written as follows:

$$\overline{a_1}(t) \le \overline{S_1}\hat{X}_t \le \overline{a_2}(t) \tag{15}$$

$$\overline{\varphi_1}(\hat{X}_t, t) \le \overline{S_2}U_t \le \overline{\varphi_2}(\hat{X}_t, t) \tag{16}$$

IV. THE RESULTS OF EXPERIMENTAL ANALYSIS AND APPLICATION OF PREDICTIVE CONTROL ALGORITHMTO APPLIED TASKS

Currently, the scope of practical application of the control method with predictive models has expanded significantly, covering not only the various technological processes in the chemical and construction industries.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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Industries, light and food industries, in aerospace research, in modern energy systems. But also economic processes, for example, management production and a portfolio of securities [5,7].

This section provides an example of the synthesis of control of a second-order nonstationary object with a predictive model based on output tracking.

$$x_{t+1} = \begin{bmatrix} 0{,}85 + 0{,}05\sin(0{,}8t) & 0 \\ 0{,}8 & 0{,}95 \end{bmatrix} x_t + \begin{bmatrix} 0{,}15 \\ 0{,}25 \end{bmatrix} u_t, \quad x_0 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \qquad (17)$$

$$\Psi_t = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x_t + v_t, \qquad (18)$$

$$y_t = \begin{bmatrix} 1 & 0 \end{bmatrix} x_t, \qquad (19)$$

where $x_t \in R^2$ is the state vector, $u_t \in R^1$ is the control, $\Psi_t \in R^2$ vector observations, $y_t \in R^1$ - output vector, noise measurements v_t, are Gaussian quantities with zero mean and covariance matrix:

$$V = \begin{bmatrix} 0{,}0005 & 0 \\ 0 & 0{,}0005 \end{bmatrix}$$

The expression (19) says that only the first component of the state vector is tracked. In this example, there are no restrictions on the state vector x_t, and the restrictions on the control are represented by the following inequalities:

$$-0{,}5 \le u_t \le 0{,}5 \qquad (20)$$

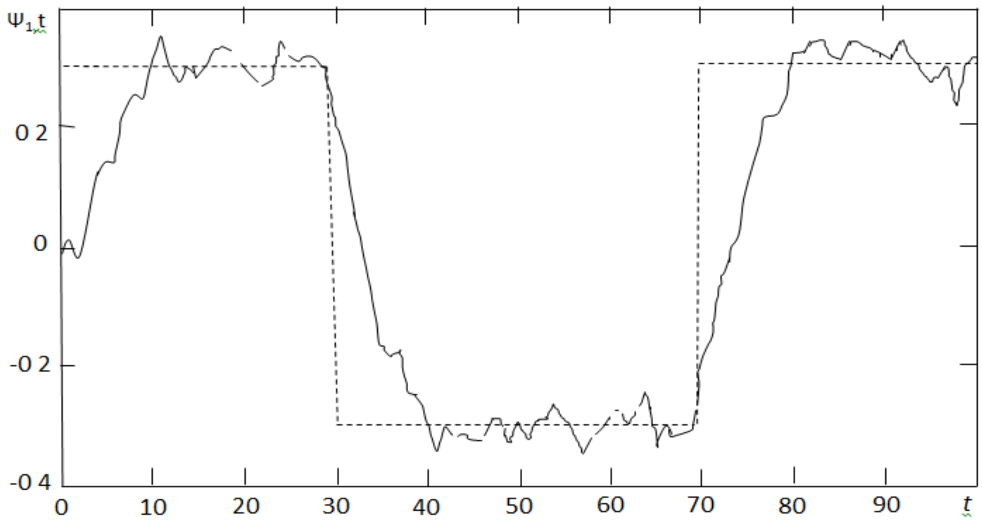
The modeling was carried out on a time interval of 100 units assuming that the control and forecast horizons are equal (M = N = 10).

The purpose of the simulation is to determine a control sequence in which the following trajectory will be traced:

$$\bar{y}_t = \begin{cases} 0{,}3 & t \ne \overline{31.70}; \\ -0{,}3 & t = \overline{31.70}; \end{cases} \qquad (21)$$

As weights of the output of the object and the control (in this case, it is the coefficients that are used, not the matrices, since the dimensions of the output vectors yt and the control ut are equal to one, that is, dim(yt)= dim(ut)=1) C=D=1.

In Picture. 1 shows a graph of monitoring the monitored variable.



Picture - 1. Implementing Tracked Observations variable

- - - - set trajectory (desired),

____ observations the first component.

ISSN: 2350-0328
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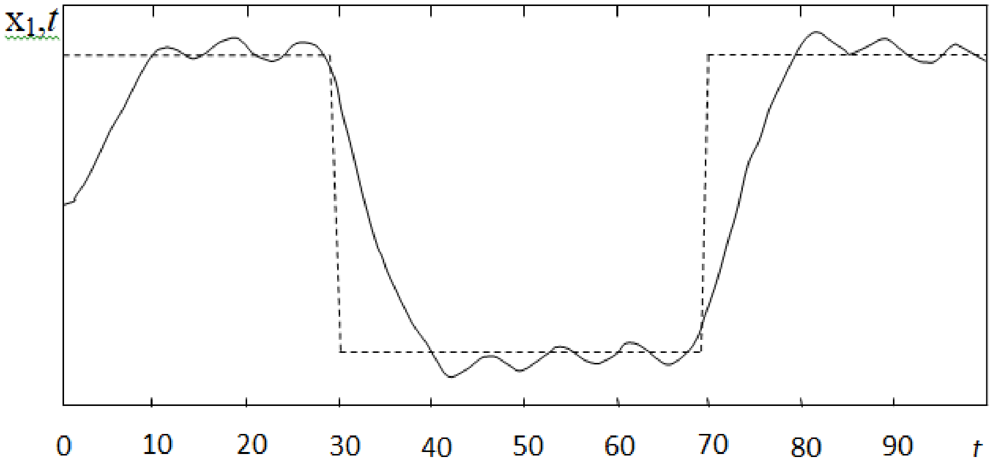
In Picture. 2 shows the behavior of the first (monitored) components of the state vector

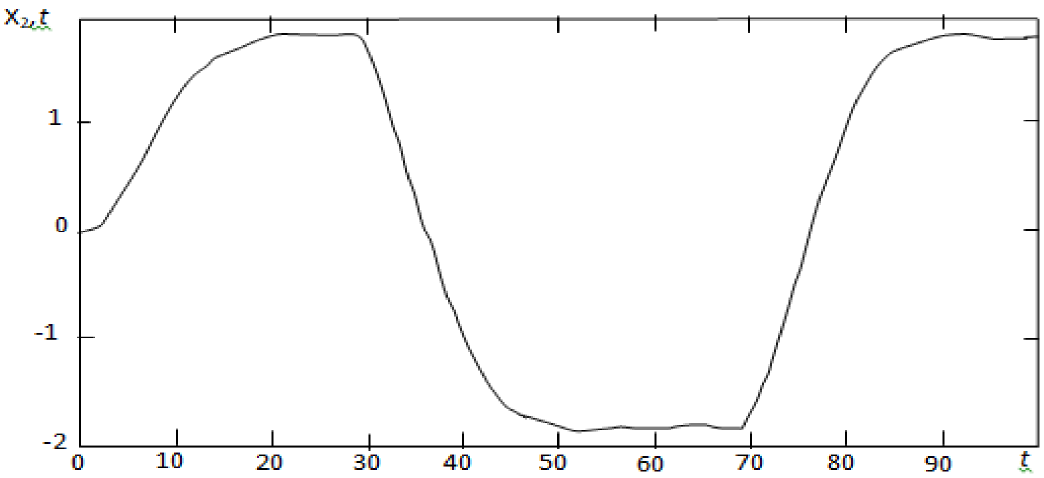


Picture - 2. Dynamics of the first state component

- - - - set trajectory (desired),

______the first component of the state.

In Picture. 3 show the behavior of the second (not monitored) components of the state vector.



Picture - 3. Dynamics of the second state component

In Picture. 4 show a graph of control actions on an object.

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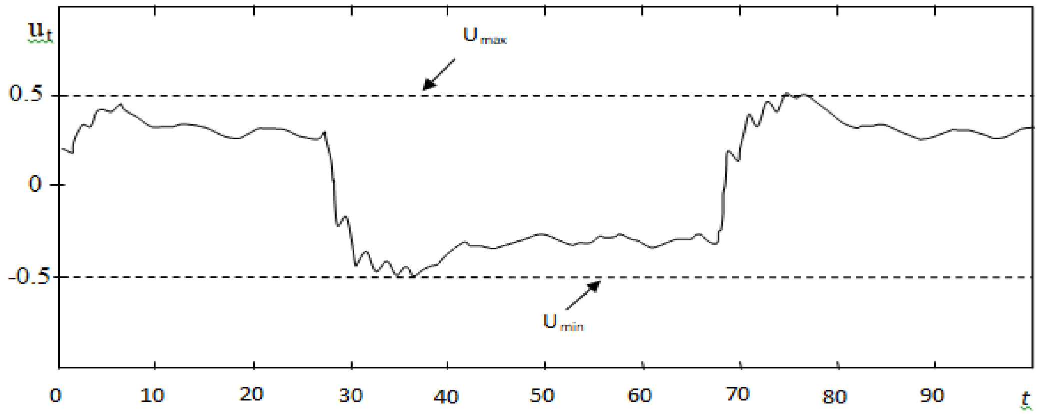

Picture - 4. Object management dynamics

- - - - restrictions on management.
____ management.

Picture 1 and 2 show that the desired trajectory is tracked when this control constraints are met (Picture 4). Proceeding from theoretical positions and analytical results of known works, the model of non-stationary discrete system under conditions of constraints and delays is proposed. Conditions for existence and explicit form of scalar control for a non-stationary system are determined.

V. CONCLUSION

Algorithms for predictive control synthesis have been developed. Output of discrete non-stationary objects with random perturbations under conditions of indirect observation of the state under restrictions on the control and state of the object.

In contrast to the classical restrictions on control (the boundaries are independent of the state vector), in this , the problem with general constraints is solved. Here, the left and right boundaries for the control are state-dependent functions. Model results were determined using the MATLAB system.

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