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NUMERICAL MODELING OF NONPARAMETRIC DUAL REGULATOR FUNCTIONING ON EXAMPLE OF FIRST-ORDER CONTROL OBJECT

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Abstract. In this article the description and test results of one of the approaches to non-parametric industrial control systems are given. The testing of such system was held when keeping the set point as polinomial, exponential and piecewise-linear functions. Unlike widely spread PI- and PID-regulators, the regulation error in such system was under 5.3 per cent without re-adjusting regulator parameters and changing the structure of the system.

Keywords: nonparametric model, dual approach, inputs-outputs matrix, extended matrix

Introduction. The key task to solve the problem of control any technological process is to make its mathematical model. Now most approaches to achieve the model are based on making their equations. The elements of these equations are some parameters of the system, whose values are accepted to be equal some defined value. Bit in real production conditions these values change during the technological process. Thus, there is the necessity to improve present approaches by means of applying nonparametric approach to making the model of control object.

In [1] the main principles of nonparametric control systems are described. In [2] there is the description of some main aspects of nonparametric regulators synthesis. But in both sources the Duhamel's integral is used to achieve. It is connected with the linear chapter of control theory. This means that achieved results cannot be correct in case of systems with vector inputs and outputs. In addition, such models are not global both in time and state space of controlled system. It is necessary to give credit to author of work [1], who was one of the first to set out his considerations as to real problems of synthesis of control objects models, which represent the state of things adequately. In whole, the research line connected with development of nonparametric control systems to which the neural networking structures can be put down is positive. Actually, mentioned approaches are the varieties of dual approach [3, 4].

Materials and methods. In the present work the task to demonstrate the high efficiency of application of the nonparametric dual control approach on the number examples is set, the idea of what is set in [5, 6].

Concept description. To ease the realization of the results of this work, without necessity for the reader to look for contents of [5, 6], let us describe the main ideas of algorithm of dual nonparametric controller. As control object model the next difference equation was taken:

$$X[n+1]=aX[n]+bU[n], \qquad (1)$$

where *a*, *b* – coefficients, changing of which is not provided, so they are not included in synthesized regulator equation.

The technological process data are measured every fixed time interval *dt=const*. As a result we achieve the extended matrix of the following view:

$$\begin{array}{ccc} X[n+1] & X[n] & U[n] \\ X[n] & X[n-1] & U[n-1] \\ X[n-1] & X[n-2] & U[n-2] \end{array}, \qquad (2)$$

where *n* is the number of time interval with the length of *dt; X[n+1]*, *X[n]*, *X[n-1], X [n-2]* – are the values of output variable *X* on the respective steps (intervals)

As this takes place, *X*[*n+1*] is the desirable (set) value of output variable of control object on the “future” [*n+1*] time interval, *U*[*n*] is the value of control action that has to provide the desirable set value of output value. The numeration of intervals includes the condition of physical implementation.

In order to fill the extended matrix with initial data it is necessary to conduct the regulator learning by means of injection the necessary quantity of (in this case two: *U[n-1], U[n-2]*) conceptually unconditioned signals onto the object input and registering output of the control object. Thus, all action values (except *U[n]*) that are included in extended matrix (2) are known by the results of measurements on the previous steps or are set. So far, it is necessary to define the control action $U[n]$. It is calculated with the help of algorithm, that represents modified Gaussian algorithm, or other modified one, that includes the triangularization of lower left second-order sub matrix of extended matrix (2) with the corresponding transformations of control action values in the rows that correspond to selected sub matrix. As a result, the new transformed submatrix of extended matrix is achieved. After that, this matrix is brought to the first two elements of the upper row of extended sub matrix (2). The left element of this row after such transformation equals the value of control action $U[n]$. After the method application the first achieved value $U[n]$ is useable. Matrix (2) on every next step is updated with the new data about the control object state (old data is "forgot") and next value of control action is calculated accordingly to set desirable value of output variable $X[n+1]$.

It should be mentioned that matrix (2) dimensions may be varied accordingly to control object order regardless of the fact it is linear or nonlinear. Moreover, this variation may be applied during the control process, which is quit of the trouble of control object order and structure definition. And this algorithm is easily programmed for control objects of every order. As a result, specific numerical values of control action are achieved.

For mentioned simple example for visualization the transformation of matrix (2) was performed and the equation of control action in analytical view. The control action $U[n]$ is calculated by the following formula:

$$U[n]=U[n-1]*[X[n+1]/X[n]]-[[[U[n-2]*X[n]]-U[n-1]*X[n-1]]*[X[n-1]*X[n+1]-X[i]*X[n]]]/[[X[n-2]*X[n]-X[n-1]*X[n-1]]*X[n]]. \qquad (3)$$

The discretization time step dt is not included in the regulator equation directly. Its value is determined by the frequency of sensor inquiry. Changing the dt value influences the matrix (2) value changing, thereby it is taken into consideration.

The testing of control algorithm (3) for different laws of set value $X[n+1]$ was held: constant, linearly growing, linearly lowering function, parabolic of different powers, exponential. It is known from the control theory that it would be necessary to change the structure of the regulator when using the proportional-integral regulation in order to achieve the regulation error tended to zero.

Moreover, this concerns only of the polynomial laws of output value. After that, if the control object parameters were varied with time or space (e.g. with output value), it would be necessary to change the parameters of such regulator. Otherwise the regulation error tends to infinity. As it is seen from the algorithm of nonparametric dual regulator (3) its construction doesn't imply such concepts as regulator coefficients and is connected with the set form of the desired regulation law in no way. Actually, this means invariance with respect to mentioned factors. This can be considered as its additional advantage.

It should be also mentioned that when controlling a unstable object the problem of minimization the error in case of using the traditional regulators intensifies. Further we'll show the results of numeric modeling of nonparametric dual regulator when having the above-mentioned problems. These results make it possible to compare the functioning of such regulator and the one of traditional regulators and to make corresponding conclusions.

To test algorithm function several signals of different forms were injected onto control object input:

- Constant signal (fig.1)
- Signal varied by the set law (fig.2)
- Quadratic parabolic signal (fig.3)
- 4-power-parabolic signal (fig.4)
- Exponential signal (fig.5)

Control actions and output signals by corresponding input actions. In fig. 1 (1-5) in graphical view the system response to corresponding input signals is given. In all described cases a coefficient was assumed $a=10$, i.e. control object was unstable. In the lower part of the window the regulation error value when applying described approach is shown. This error reaches zero value when injecting constant signal onto control object input. Maximum error value is reached when injecting trapezium-like signal onto the input of control object.

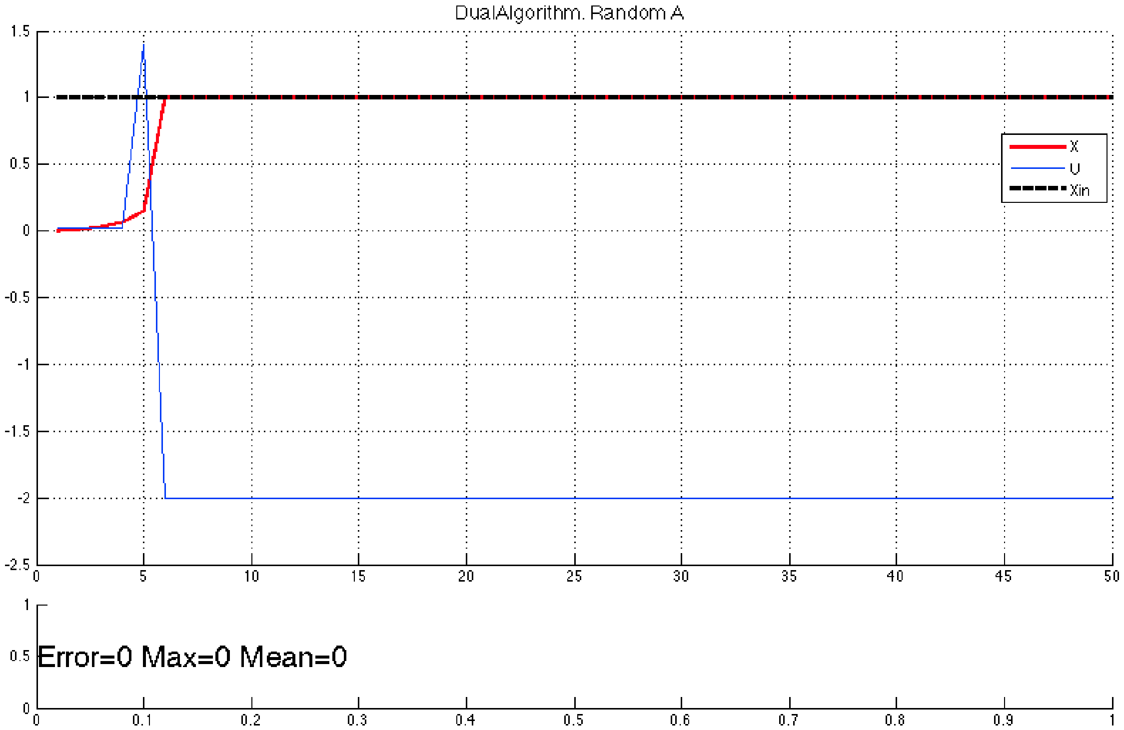

Figure 1. Control action U, set point Xin, output signal X when injecting constant input signal

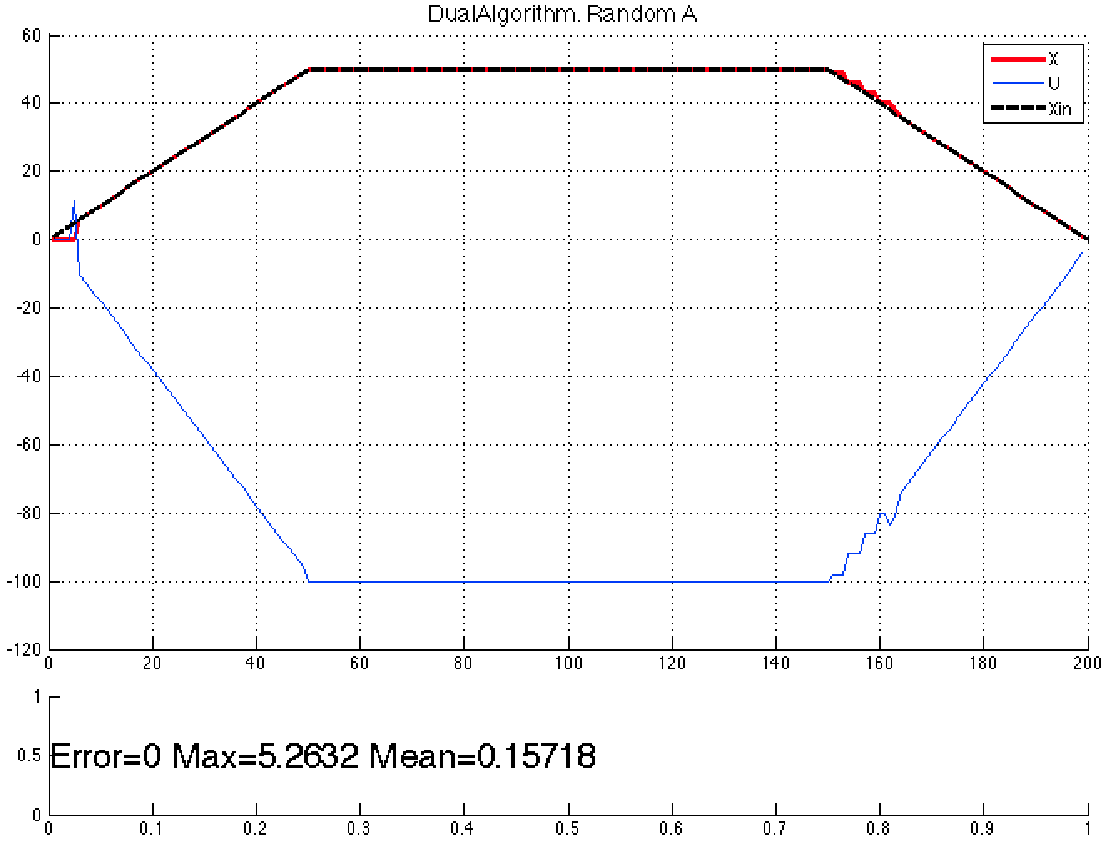

Figure 2. Control action U, set point Xin, output signal X when injecting input signal changed by definite law

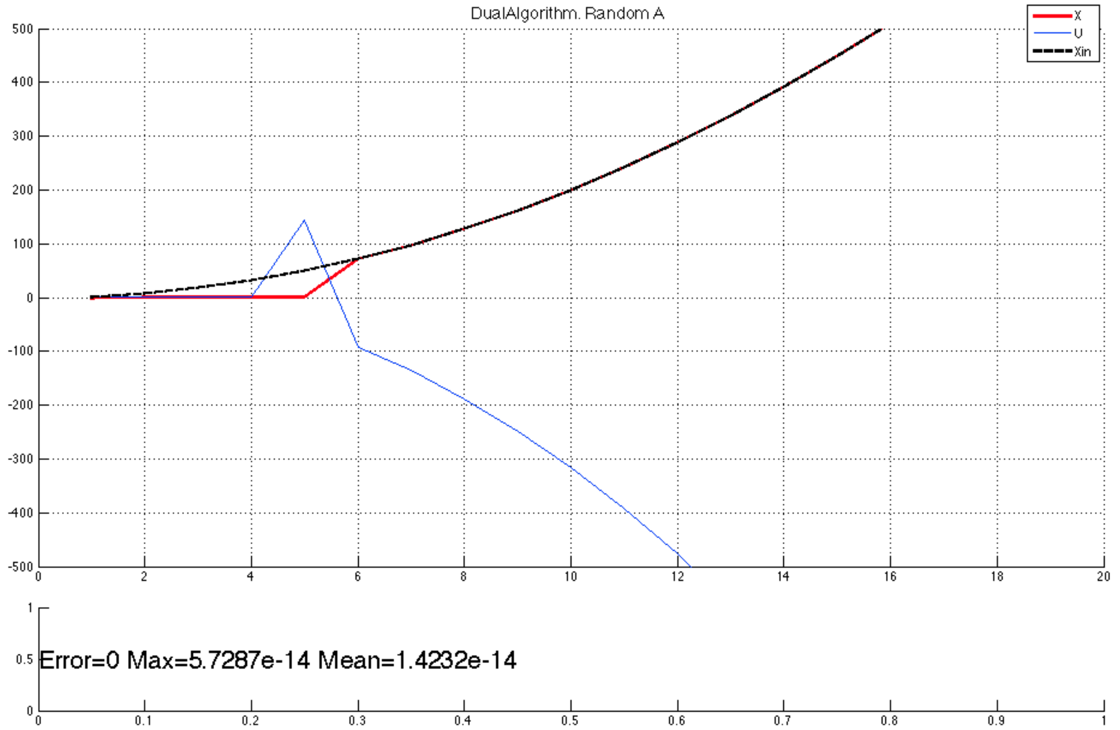

Figure 3. Control action U, set point Xin, output signal X when injecting quadratic parabolic signal

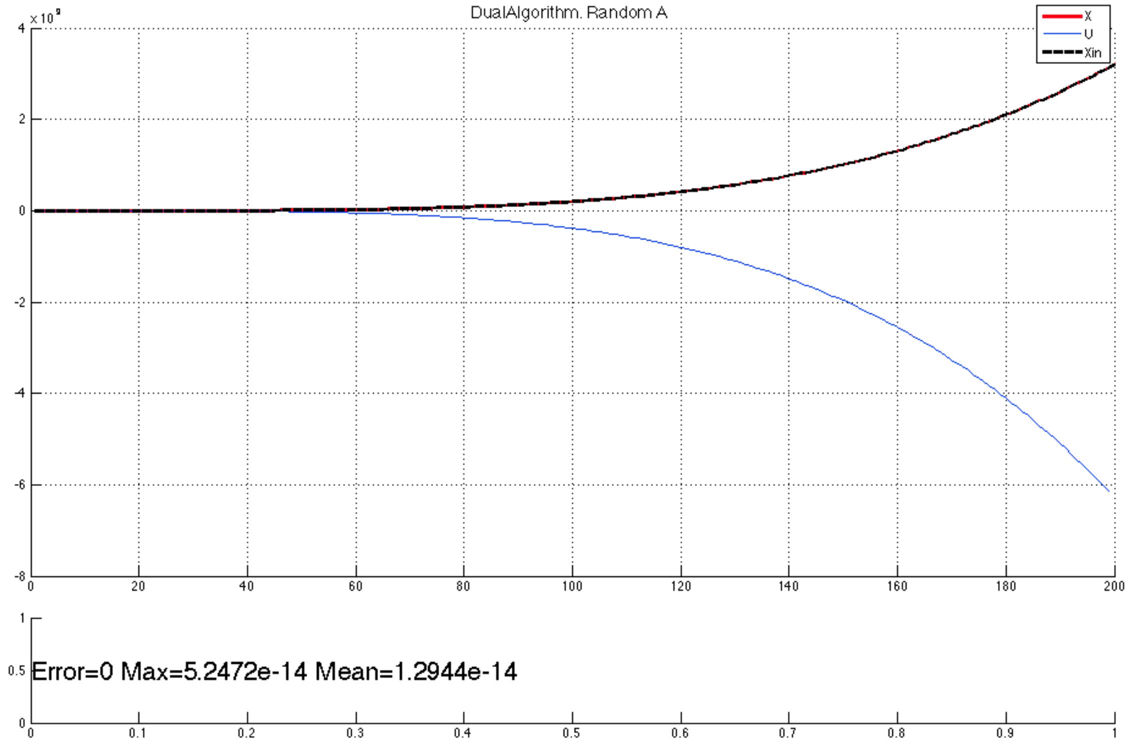

Figure 4. Control action U, set point Xin, output signal X when injecting 4-power-parabolic signal

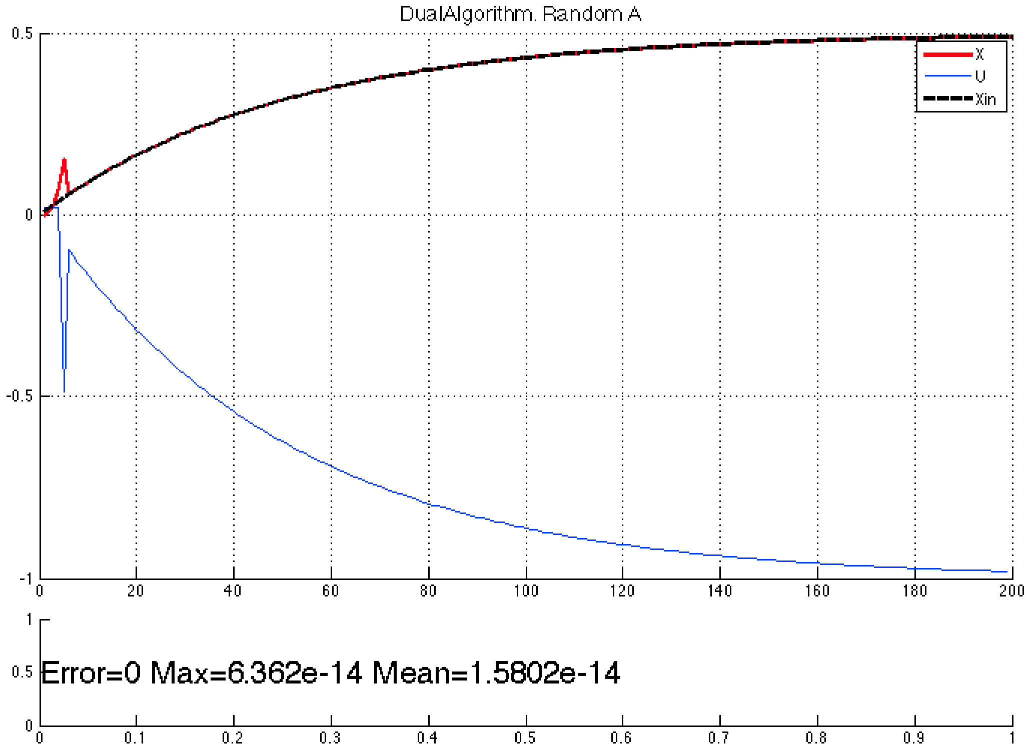

Figure 5. Control action U, set point Xin, output signal X when injecting exponential input signal

It should be mentioned that control value spikes of definite range are seen during initial steps. This is typical for the learning stage of the controller, so it is normal. For every demonstrated case the number of learning steps was equal to 5.

In the future we plan to research this algorithm when using limitations as to the control value and its increase per time unit (steepness).

Table 1. Function Errors of proposed system when applying different input actions.

Input action	Relative Error (%)		
	Min	Max	Mean
Constant	0	0	0
Law	0	5.2632	0.15718
Quadratic parabola	0	5.7287e-14	1.4232e-14
4-power-parabola	0	5.2472e-14	1.2944e-14
Exponent	0	6.362e-14	1.5802e-14

Conclusions. Proposed nonparametric dual control algorithm has essential advantages comparatively to traditional PID-regulators, providing practically zero error during little period of time when applying different input actions and using different parameters even in the instability range without need to chnge the structure of regulator and its readjusting. The regulators of such type advantageously differs from neuro-controllers with short training set

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