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ADAPTIVE DB(n) ALGORITHM WITH ANTIWINDUP

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Abstract: This paper describes DB(n) control algorithm extended on Antiwindup and state space version of algorithm. Author derived extended version of algorithm. This version of algorithm in conjunction with on-line identification has the adaptive self-tuning performance. The synthesis was derived for control loop with proportional third order behaviour of controlled plant. However, the algorithm can be applied for plants with higher order and plants with non-minimal phase or dead time, as is shown in simulation experiments. Simulation experiments were performed on analogue model of controlled plants as hybrid simulation in real time and are commented in the paper

Key words: DB control, sampling interval, control synthesis, simulation.

1 Introduction

Discrete version of time optimal control or DB(n) algorithm is in general known as elementary control algorithm. Its disadvantages are eliminated in extended DB(n) algorithm derived by author. Author derived two extension of algorithm. First is antiwindup extension of classical DB(n) algorithm (eDB(n) algorithm). The second extension is state space version of DB(n) algorithm with antiwindup [Alexík 2001-1]. This algorithm is the best one from algorithms operating only with output from controlled process. Real time continuous identification of plant parameters consecutiveness of control algorithm parameters synthesis enabled us to realize adaptive control with described algorithm [Alexík 1997] and also with eDB(n). Although the synthesis of eDB(n) was derived for control loop with proportional third order behaviour of controlled plant, adaptive eDB(n) algorithm can be applied also for plants with higher order and plants with non-minimal phase or dead time, as is shown in simulation experiments. Verification of adaptive eDB(n) algorithm was carried out by block scheme depicted in Figure 1. Simulation mode depicted on Figure 1 is called also hardware in loop simulation or hybrid simulation [Alexík 2001-3]. Hybrid simulation increases motivation of students and research workers during laboratory verification of algorithms.

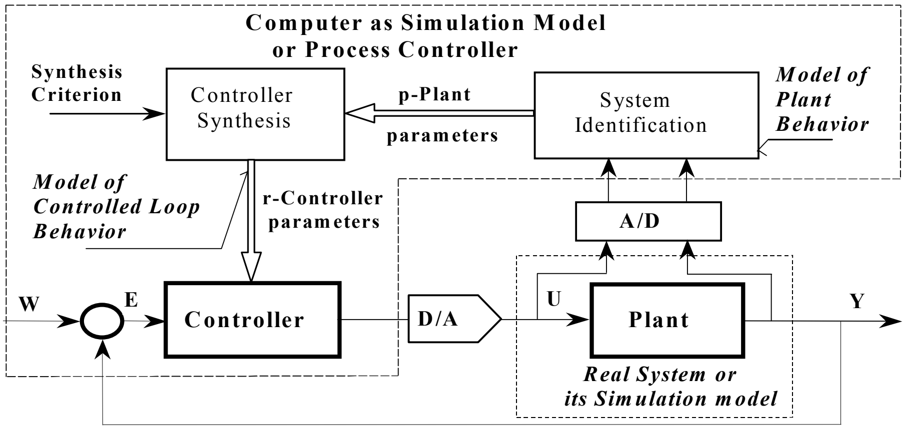

Figure 1. Hardware in loop simulation of adaptive control.

The paper is organised as follows. In section 2 there is described equations of both version of eDN(n) algorithm, section 3 describes analogue model of the controlled plant used for hybrid simulation and section 4 describes real time simulation experiments according to the block scheme in Figure 1. The paper ends with conclusion and outlook in Section 5.

2. Extension of DB(n) algorithm.

Synthesis of parameters for known structure of DB(n) algorithm is outgoing from Z transform function (1) of controlled plant. The disadvantage of DB(n) algorithm is great jump of manipulated variable request by proving for time optimal transient response of control loop. Actuating variable (3) cannot be realized in any case, considering D/A converter output limitation and followed overflow of controlled output as depicted on Figure 2.

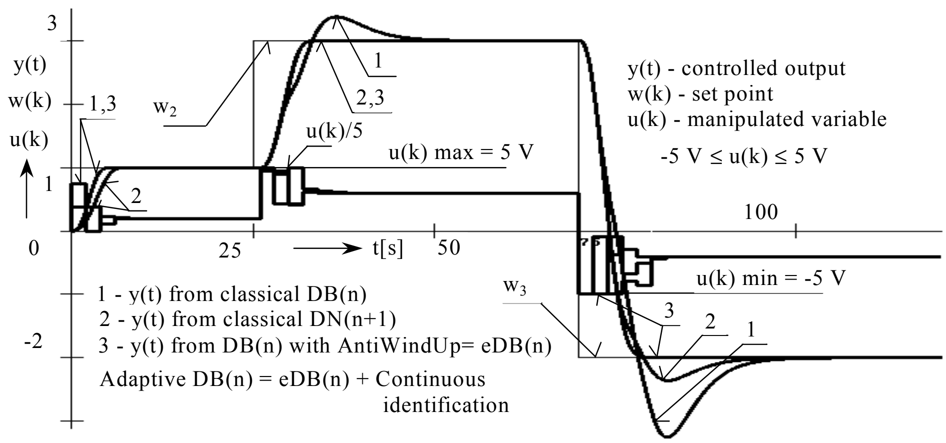

Figure 2. Comparison of classical and extended DB(n) algorithm.

In the presented eDB(n) algorithm, the most important property is ability to assure discrete time optimal control in despite of manipulated variable limitation. This is secured by extended - antiwindup part of algorithm, which was derived, as well as PID antiwindup described by author in [Zentko, Alexík 1986, Alexík 1994]. Similar behavior of feedback response is supposed to assure by modal state space algorithm, however eDB(n) algorithm (4) does not need state estimator, therefore is more easily. State space form (5) of eDB(n) algorithm is more easily because there is it one third less arithmetic operation.

$$S(p) = \frac{K}{(T_1 p+1)(T_2 p+1)(T_3 p+1)} = \frac{b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3}}{1 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3}} \quad (1)$$

$$q_0 = (1/\sum b_i);\ q_1 = q_0 * a_1;\ q_2 = q_0 * a_2;\quad q_3 = q_0 * a_3$$

$$p_1 = q_0 * b_1;\ p_2 = q_0 * b_2;\quad p_3 = q_0 * b_3 \quad (2)$$

Classical DB(n) algorithm has the form :

$$u(k) = q_0\, e(k) + q_1\, e(k-1) + q_2\, e(k-2) + q_3\, e(k-3) + \\ + \left[p_1\, u(k-1) + p_2\, u(k-2) + p_3\, u(k-3)\right] \quad (3)$$

Extension of DB(n) algorithm for manipulated variable constraint has the form :

$$u(k) = q_0\, e(k) + q_1\, e(k-1) + q_2\, e(k-2) + q_3\, e(k-3) + \\ + \left[p_1\, u(k-1) + p_2\, u(k-2) + p_3\, u(k-3)\right] - \\ - \left[q_{d1}\, u_d^o(k-1) + q_{d2} u_d^o(k-2) + q_{d3}\, u_d^o(k-3)\right] \quad (4)$$

$q_{di} = p_i + q_i / q_0$; $u^o(k)$ - D/A converter constraints; $u_d^o(k\text{-}1) = [u(k\text{-}1) - u^o(k\text{-}1)]$;

State space form of extended DN(n) algorithm has the form :

$$x_3(k) = p_3 x_1(k-1) + p_2 x_2(k-1) + p_1 x3(k-1) + e(k)$$

$$u(k) = q_0\, x_3(k) + q_1\, x_3(k-1) + q_2\, x_2(k-1) + q_3\, x_1(k-1) \quad (5)$$

$$\text{if } |u(k)| > |u^o(k)| \text{ then } x_3(k) = x_3(k) - (1/q_0)[u(k) - u^o(k)]$$

3. Analogue model of the process

For evaluation of control algorithms, the hybrid simulation in comparison with the digital one is more suitable. In our case it is the continuous process modelled with the continuous model working in real time. The technical design of the continuous model enables us to model the proportional linear system of the first to the sixth order and also to change the parameters and the structure of the controlled system, which is suitable for the evaluation of robustness of the control algorithm. Figure 3 shows and describes the model. The dynamics of the process realised with the model under Figure 3 is described with transfer functions of the second and first order. During the transient state, it is possible to change the relative damping for the second order system (S_1) or time constant of the second or first order and the total gain or order of the system from the first to sixth orders. It is also possible to connect model as the MIMO system with 2 inputs and 2 outputs. The individual models can be connected to the input of the gain block, which is marked in Figure 3 as "U".

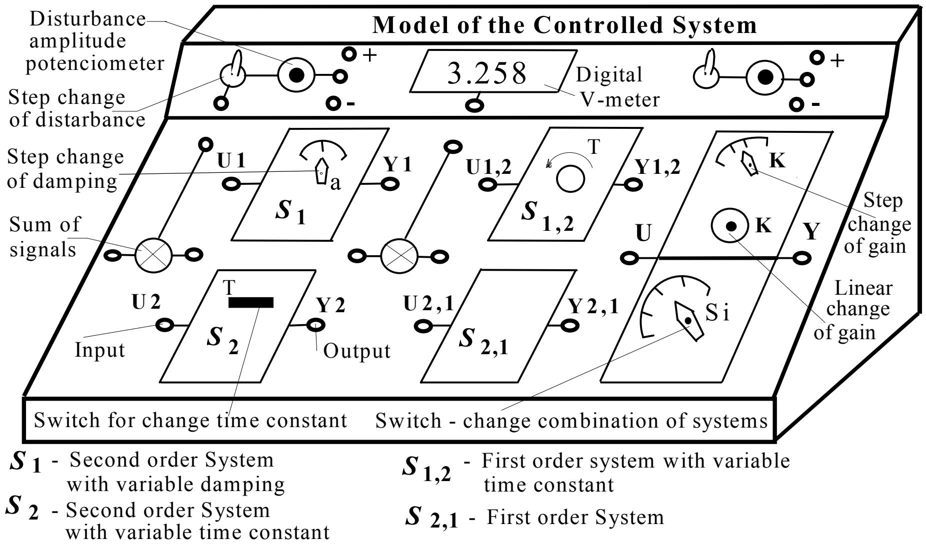

Figure 3. Model of the controlled system.

Then it is possible to change the system gain during the transient state in a continuous or step manner. The switch *Si* enables to combine individual transfer functions in such a way that the "Y" output has dynamic characteristics of the proportional system till the sixth order. This kind of model of the controlled plant enables us to change individual time constants, gains and structure of the controlled system in a continuous or step-by-step manner. Transient responses of applied analogue model are depicted on Figure 4.

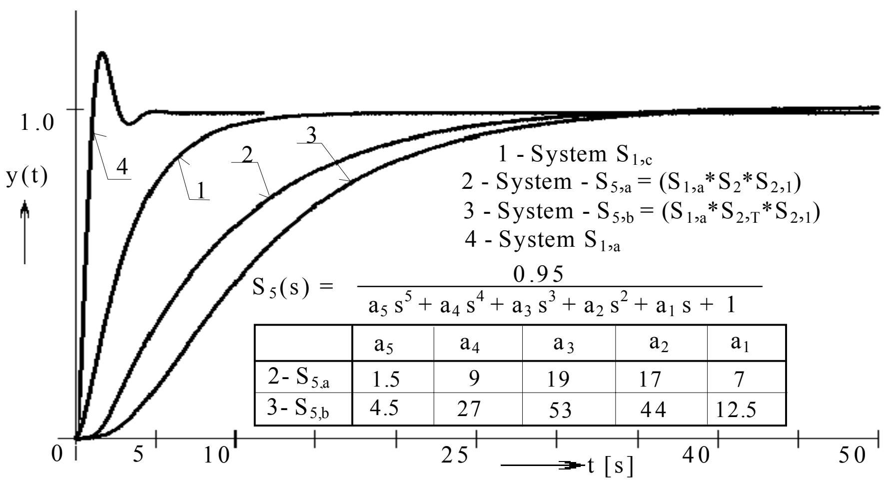

Figure 4. Transient responses of the realised second and fifth order systems.

4. Real time simulation experiments description.

Real time simulation experiments are called also hardware in loop simulation or hybrid simulation, because controlled variable is scanning in real time by A/D converter from hardware realized analogue model of controlled plant described in previous section. Real time continuous identification of plant parameters consecutiveness of control algorithm parameters synthesis enabled us to realize adaptive control with described algorithm [Alexík 1997]. By using this approach the controller is updated every sampling interval and the incoming input-output information are capable to improve the parameter estimation process [Alexík 2001]. In principle, the on-line mathematical model of controlled plant and on-line synthesis of control algorithm for demanded quality of control process were suggested. This advance is called Self-Tuning Control (STC) or indirect adaptive control. Example of real time simulation experiment with continuous identification and control from Figure 5 demonstrates aptitude of proportional third order controlled plant model apply for control loops with higher order of plant.

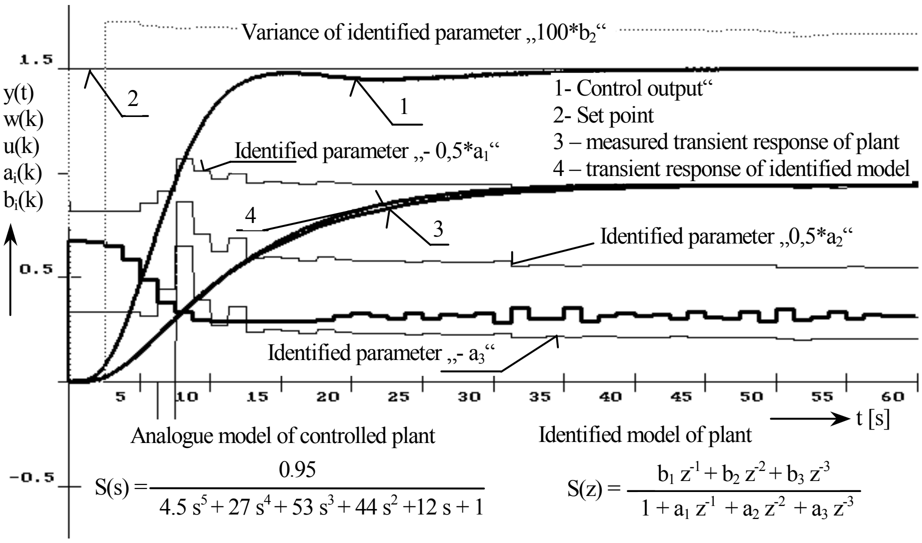

Figure 5. Adaptive identification and control with eDB(n) algorithm.

Specific problems are also with the start of adaptation. In the first seven to several tenth steps (it depends from error of identification, which is computed), PD algorithm with varying gains was applied. In this case, there is a problem with adaptive computing of gains and identification error depending on sampling interval and identified parameter of plant. This problem is not resolved at this time well and coefficient of varying gains and an error of identification when adaptation process is started have to be taken ahead of start of simulation experiment. Comparison of computer simulation and hybrid simulation of adaptive eDB(n) control, including identified parameter tuning by hybrid simulation, is shown in Figure 6. As controlled plant there is analogue model $S_{5,b}$ from Figure 3 and Figure 4.

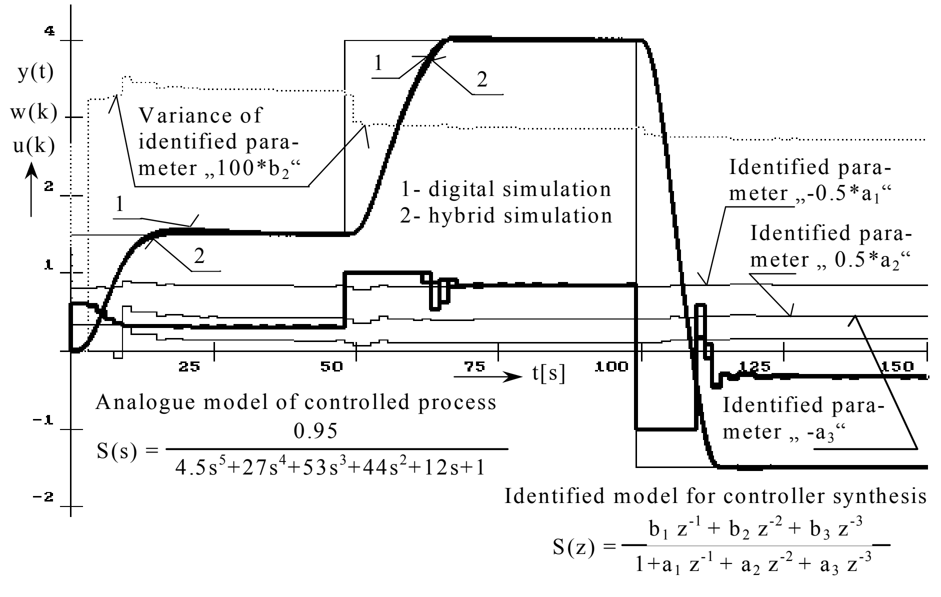

Figure 6. Comparison of digital and hybrid simulation by adaptive DB(n) algorithm

From Fig. 7 is evident, that eDB(n) algorithm enables good quality of controlled loop behaviour for several sampling intervals and higher orders of controlled plant as were assumed for controller synthesis. However, two problems must be solved more completely: continuous identification algorithm, applicable for wide scale of sampling interval and for identification of variable dead time of controlled plant.

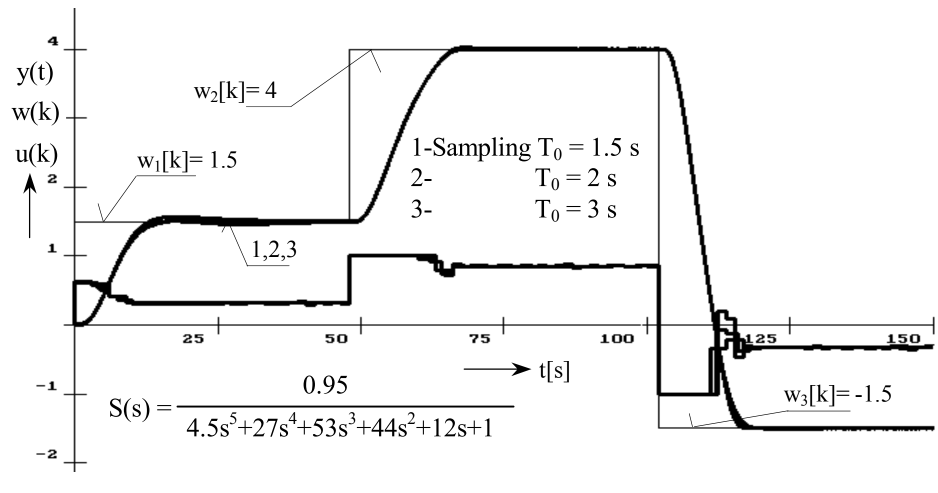

Figure 7. Comparison of change sampling interval by adaptive DB(n) algorithm

The next simulation experiment shown at Figure 8 is digital (not hybrid) simulation of adaptive control of plant with non-minimal phase for three different sampling intervals. To control such a type of plant is very difficult, but from Figure 8 it is evident, that described algorithm provides very good quality of controlled loop response. The start of adaptation process (time interval 0-20 [s]) is the weak point of all adaptive control algorithms.

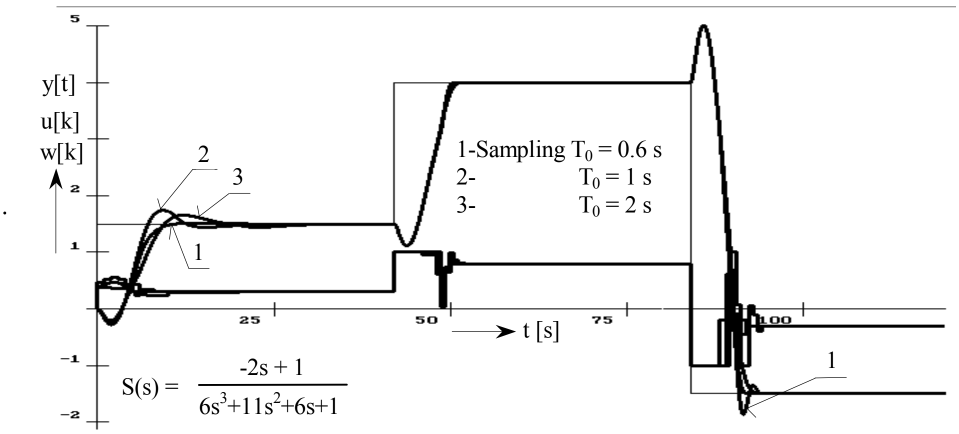

Figure 8. Discrete simulation –adaptive eDB(n) control of the non-minimal phase plant.

In the last picture, there is shown discrete simulation of plant with transport delay. There is adaptive control but in advance identification for adaptive control it is appropriate to expand continuous identification by immediate estimating of dead time. Fig. 9 documented application possibility of described algorithm also for plant with dead time.

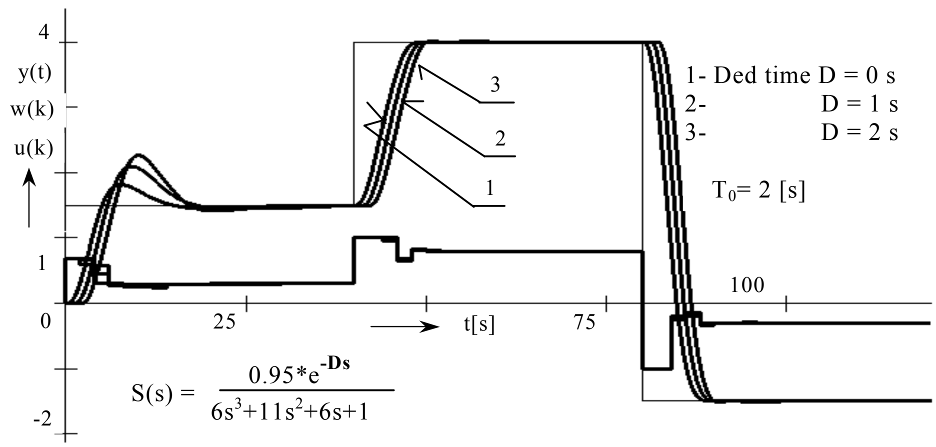

Figure 9. Discrete simulation –adaptive eDB(n) control of the plant with dead time.

5. Conclusion and outlook.

Based on present experience, the laboratory verification and teaching of control algorithms on described hardware in loop simulation provides good results. This way, there were verified classical and adaptive PID, PIDD^2, DB(n), eDB(n) algorithms, state algorithms, sliding mode and self-tuning PID algorithm. In this paper, there is described adaptive eDB(n) algorithm. Simulation experiments were realised in program environment of ADAPTLAB, developed and realised by author. It is suitable for developing and verification of classical as well as adaptive control algorithms for SISO and MIMO control loops. The program can be used in two basic modes: simulation and measurement. The simulation mode works with continuous transfer function set by operator. In the measurement mode the output (input) from model of the plant described in Section 3 is measured with A/D (D/A) converter with sampling interval controlled by real time clock or interrupt from A/D converter. Up to now experience of author showed, that hybrid simulation is more appropriate as digital simulation both for verification and teaching.
In future, the author will focus on research of self-tuning algorithms, start of adaptation problem and variable dead time delay identification.

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