Double Expert System for Monitoring and Re-adaptation of PID Controllers

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Abstract. Finding of monitoring systems for deciding if or how re-adapt a PID controller in literature is not so complicated. These monitoring systems are also widely used in industry. But monitoring system which is based on non-conventional methods for deciding, takes into account the non-numeric terms and it is open for adding more rules, is not so common. Presented monitoring is designed for systems of second order and it is performed by the fuzzy expert system of Mamdani type with two inputs - settling time compared with the previous settling time (relative settling time) and overshoot. It is supplemented by using of non-conventional method for designing of classic PID controller. So it can be called as double expert system for monitoring and following re-adaptation of classical PID controller. The proof of efficiency of the proposed method and a numerical experiment is presented by the simulation in the software environment Matlab-Simulink.

Keywords: Monitoring, re-adaptation, expert system, knowledge base, PID controller, Ziegler-Nichols' combinated design methods, fuzzy system, feedback control.

1 Introduction

The paper is focused on adjustment of the monitoring system for deciding when re-adapt the classic PID controller. Presented monitoring system (Figure 1) has some common elements with [1]. It is created fuzzy expert system of Mamdani type (ES1) with two inputs - overshoot and settling time, but settling time is not defined as a classic time, but as the part or multiple of previous measured settling time (relative settling time) and one output - score. So there are monitored simply obtained process parameters. The score determines if is necessary to re-adapt the controller.

The following design of parameters of classic PID controller is done by the second fuzzy expert (ES2) system with a knowledge base is built on know-how obtained from the combination of the frequency response method and the step response Ziegler-Nichols design method [2].

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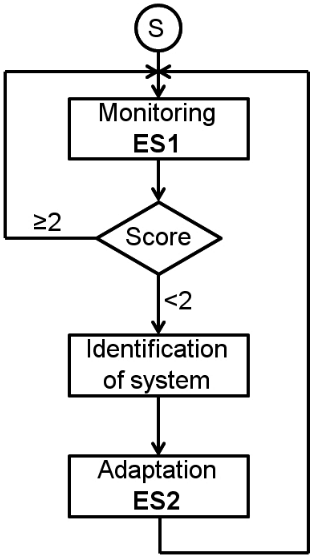

Fig. 1. The flowchart of monitoring and re-adaptation procedures

2 Monitoring System

The monitoring system is fuzzy expert system [3], [4], [5] of Mamdani type with two inputs, knowledge base with linguistic rules and one output and it has been created and the efficiency is proofed for controlled systems of the second order with transfer function in the form

$$G_S(s) = \frac{1}{a_2 s^2 + a_1 s + a_0}. \tag{1}$$

2.1 Inputs – Relative Overshoot and Relative Settling Time

The first input is the linguistic variable relative overshoot (RO) - the difference between the controlled value (CV) and the required value (RV) is rated relatively to the required value (2).

$$RO = \frac{|CV - RV|}{RV} \tag{2}$$

The maximal overshoot of the time response of the system is detected after the fast step change of timing, the fast step changes in timing could be caused by the e.g. change of the controlled system or change of the required value. As it is expressed in percentage, it is relative overshoot (RO). The value of the overshoot is stored in the memory and then used with the settling time for determining the score.

The second input is the linguistic variable relative settling time (RST). As the name says, it is not the classic settling time (ST_k), it is defined as the part or multiple of previous settling time $(ST_k - 1)(3)$. So the classic settling time is also stored in the memory as the overshoot, but the linguistic variable relative settling time is defined as the ratio of current settling time and previous settling time.

$$RST_k = \frac{ST_k}{ST_{k-1}} \tag{3}$$

For evaluation of the settling time the 3 % standard deviation from steady-state value [6]. The linguistic values of both linguistic variables are expressed by fuzzy sets, for each linguistic variable by three linguistic values (Figure 2,3).

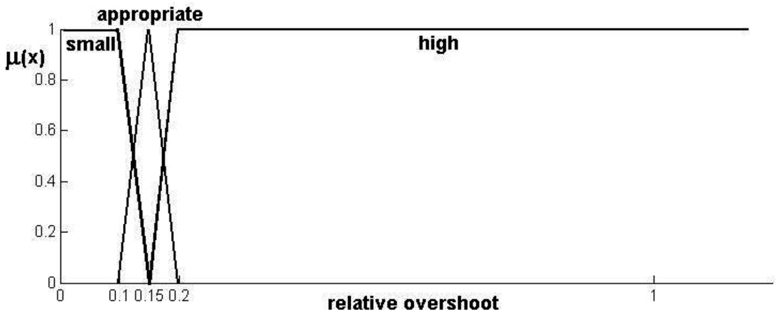

Fig. 2. The shape of the membership functions of linguistic values for input linguistic variable Relative Overshoot (RO)

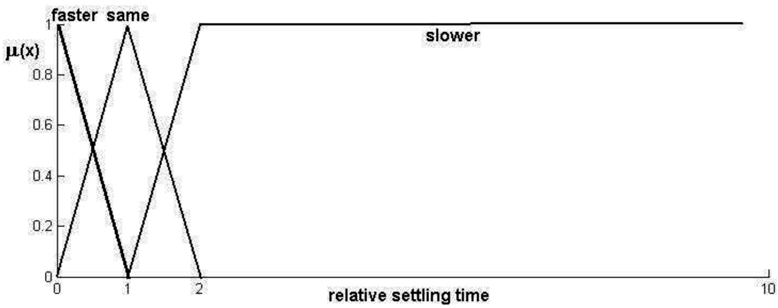

Fig. 3. The shape of the membership functions of linguistic values for input linguistic variable Relative Settling Time (RST)

2.2 Output – Score

The output of the monitoring fuzzy expert system is the score, which is also the linguistic variable and its linguistic values are expressed by fuzzy sets (Figure 4). As the fuzzy expert system of Mamdani type is used [7], the linguistic variable score must be defuzzificated. For defuzzification it is used the COA method (Center of Area) [8]. The score more than 2 means that the time response with

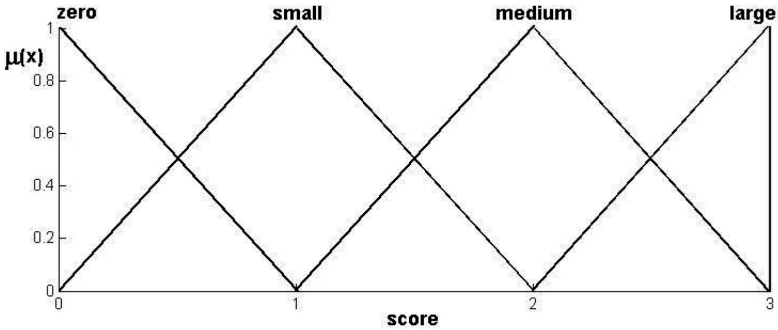

Fig. 4. The shape of the membership functions of linguistic values for output linguistic variable Score

the current controller can be considered as appropriate. The score less than 2 is considered as not satisfactory and the controller has to be re-adapted [1].

2.3 Knowledge Base

The knowledge base is formed by nine linguistic IF-THEN rules of the Mamdani type [8]:

1. If (*RO* is *Small*) & (*RST* is *Slower*) then (*Score* is *Medium*)
2. If (*RO* is *Small*) & (*RST* is *Same*) then (*Score* is *Large*)
3. If (*RO* is *Small*) & (*RST* is *Faster*) then (*Score* is *Large*)
4. If (*RO* is *Appropriate*) & (*RST* is *Slower*) then (*Score* is *Small*)
5. If (*RO* is *Appropriate*) & (*RST* is *Same*) then (*Score* is *Medium*)
6. If (*RO* is *Appropriate*) & (*RST* is *Faster*) then (*Score* is *Large*)
7. If (*RO* is *High*) & (*RST* is *Slower*) then (*Score* is *Zero*)
8. If (*RO* is *High*) & (*RST* is *Same*) then (*Score* is *Small*)
9. If (*RO* is *High*) & (*RST* is *Faster*) then (*Score* is *Medium*)

The shape of membership function of output variable is inferred using the Mamdani method. The crisp value of the output score is determined using the defuzzification method Center of Area [8].

3 PID Parameter Design System

As it was mentioned also for design parameters of conventional PID controller fuzzy expert system (ES2) is used [2]. It uses know-how obtained from the combination of the frequency response method and the step response Ziegler-Nichols design method. [6], [9]

The constant a_2, a_1 and a_0 from the denominator of the transfer function of the controlled system (1) are the inputs of the expert design systems (ES2) (Figure 5). The input parameters a_2, a_1 and a_0 are the linguistic variables expressed

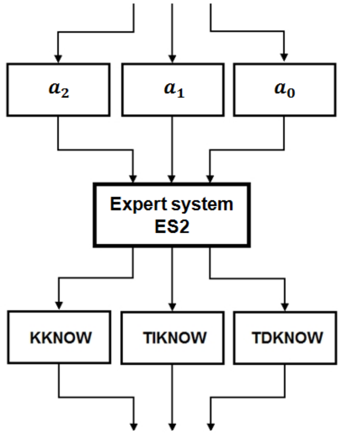

Fig. 5. Graphical representation of inputs and outputs of expert system ES2 [2]

by fuzzy sets for each linguistic variable by three linguistic values - small (S), medium (M) and large (L). It can be the constants from intervals a_2 - [0; 22], a_1 - [0; 20], a_0 - [0; 28].

The outputs *KKNOW*, *TIKNOW* and *TDKNOW* of ES2, which are also constants, are the parameters of conventional PID controller with the transfer function expressed as

$$G_R(s) = KKNOW\left(1 + \frac{1}{TIKNOW \cdot s} + TDKNOW \cdot s\right). \tag{4}$$

Expert design system is model of Takagi-Sugeno type [10] so it does not require defuzzification. The knowledge base of the ES2 is consisted of 27 linguistic rules. For detailed information see [2].

4 The Description of Implemented Algorithm

It is important to define the algorithm of monitoring and following re-adaptation of the controller (Figure 1). The relative overshoot is monitored and stored in memory after every step change of controlled value. The settling time is measured also after every step change of controlled value and is assessed to the previous settling time. If these two monitored parameters are obtained the score is assessed. According to the value of the score, the identification of the system starts and the controller is re-adapted (section 2.2). The simplified model in Matlab-Simulink [11] is depicted in Figure 6.

$$Score\ \left\{\begin{matrix} \geq 2 & \text{do not re-adapt} \\ > 2 & \text{re-adapt} \end{matrix}\right\}. \tag{5}$$

For identification the stochastic identification - ARMAX method is used [12]. The re-adaptation (change of parameters of controller) procedure ES2 is done only after the change of required value.

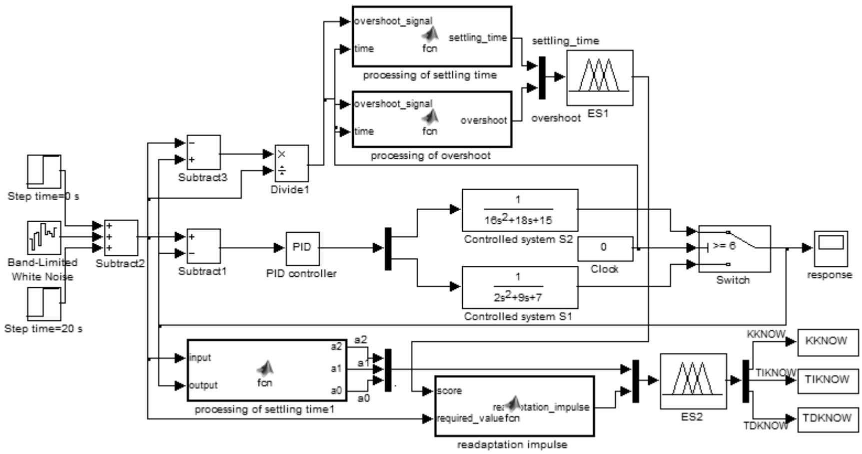

Fig. 6. Simplified model in Matlab-Simulink

5 Verification of Created System

The verification was done in Matlab-Simulink [11], the timing with description of important moments is depicted in Figure 7. Verification of the re-adaptation procedure proposed above (see Figure 1) is started using the controlled system (S1) with transfer function

$$G_{S1}(s) = \frac{1}{2s^2 + 9s + 7} \tag{6}$$

for which the controller with transfer function

$$G_{R1}(s) = 6.1\left(1 + \frac{1}{0.58s} + 0.14s\right) \tag{7}$$

designed through the identification system ES2 is used.

At the time t_A the unit step of required value is introduced. Therefore, the control process is carried out with 14%-overshoot and settling time $t_{st1} = 4.3\ sec.$ The appropriate calculated score by ES1 is

$$score_1 = 2.10 > 2, \tag{8}$$

which corresponds to the satisfactory control course.

At the time t_C a sudden change of the controlled system (to controlled system S2) is simulated from the transfer function $G_{S1}(s)$ to the transfer function

$$G_{S2}(s) = \frac{1}{16s^2 + 18s + 15}. \tag{9}$$

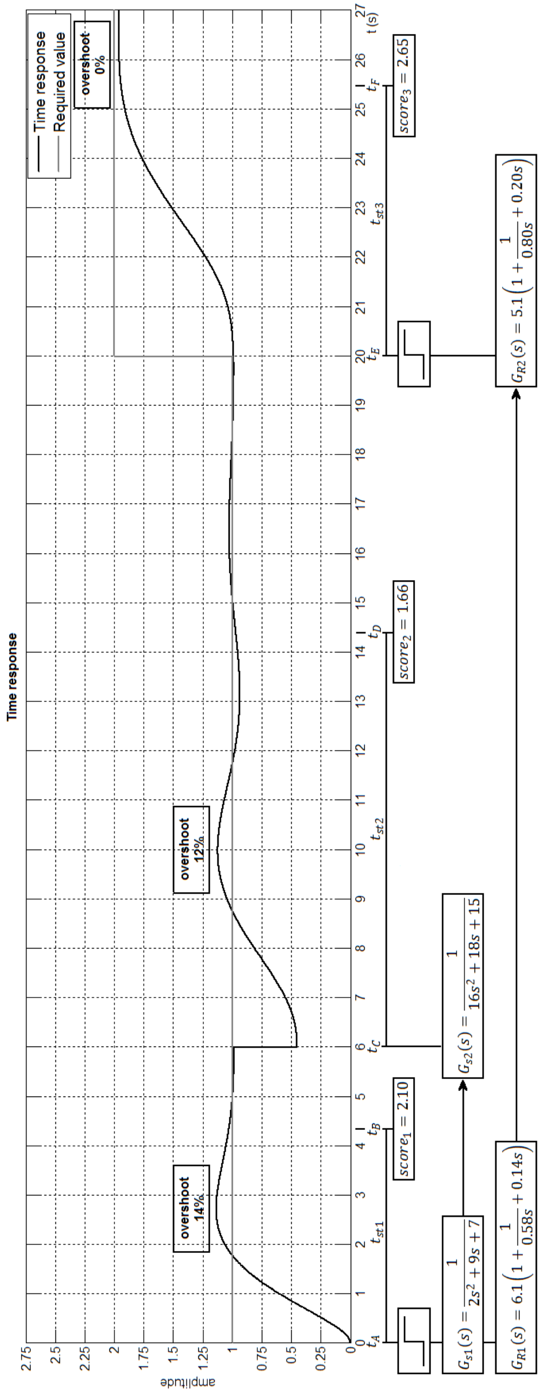

Fig. 7. Time response

Thus, a non-zero control deviation appeared which is compensated by the original controller $G_{R1}(s)$. The oscillating control course appeared with 12%-overshoot and settling time $t_{st2} = 8.4$ *sec.* Now, the calculated appropriate score is

$$score_2 = 1.66 < 2 \tag{10}$$

and insufficient control course is now indicated.

Therefore, when the nearest change of the deviation appeared at the time t_E (the unit step of reguired value is introduced) the re-adaptive process ES2 is initialized and it is designed a new controller with transfer function

$$G_{R1}(s) = 5.1\left(1 + \frac{1}{0.80s} + 0.20s\right). \tag{11}$$

Now, the control process is carried out without any overshoot and with settling time $t_{st3} = 5.5$ *sec.* The calculated appropriate score value is

$$score_3 = 2.65 > 2 \tag{12}$$

and the satisfactory control course is restored again.

6 Conclusion

The procedures of control quality monitoring and necessary re-adaptation of PID controller is solved using the fuzzy-logic principle through the rule-based expert systems. The first one concludes the initial impulse for controller adaptation. The rule base is created within two input linguistic variables - namely the relative settling time and relative overshoot are mentioned. The following design of parameters of classic PID controller is done by the second fuzzy expert system with a knowledge base which is built on know-how obtained from the combination of the frequency response method and the step response Ziegler-Nichols design method. The proof of efficiency was done using simulations in Matlab-Simulink. It is shown that presented monitoring system with following design of PID controller is useful for family of controlled systems of second order. The both described knowledge-based systems are open. Therefore, next time authors think of adding more monitored parameters and widening of family of controlled systems.

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