An Immune-Enhanced Unfalsified Controller for a High-Speed Spinning Process

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Abstract. One key process in data-driven methodology is how to use the data easily and efficiently. In this paper, an immune-enhanced unfalsified controller (IEUC) is proposed to act as an efficient process to deal with data. The IEUC consists of two parts, the first part is a unfalsified controller deriving from data-driven methodology; the second part is an immune feedback controller inspired from biologic intelligent methodology. In order to examine control effectiveness of the IEUC, we apply it to a complex plant in high-speed spinning model and compare it with a simple unfalsified control scheme. Simulation results demonstrate that the IEUC can decrease system overshoot as well as reduce rising time successfully and effectively.

Keywords: data-driven, unfalsified control, immune feedback control, high-speed spinning process.

1 Introduction

Data-driven, the beginning and the end of control process are totally based on data, is a more precise illustration of the relationship between data and control system. Data-driven control is a method which entitles data with the power of describing a control system and requires no mathematic model about control process [1].

In the past few years, data-driven methodology has aroused the interests of many researchers. Spall proposed a direct approximation control method using simultaneous perturbation stochastic approximation (SPSA) [2]. Hou and Han built the theory of model free adaptive control (MFAC) [3]. Safonov and Tsao proposed the unfalsified control (UC) [4]. Guadabassi and Savaresi proposed Virtual reference feedback tuning (VRFT) [5]. From the existing studies, we can see that present ameliorative methods could be roughly divided into three parts: the improvement on certain algorithm's performance [6-8]; the mixture of two or more control methodologies [9]; and the combination of intelligent algorithm and data-driven controller [10]. Meanwhile, an interdisciplinary method of model-based control—biologic intelligent control, a

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sophisticated process of simulate human body, is a perfect data processing system—has impressed many researchers [11].

In this paper, we present an immune-enhanced unfalsified controller (IEUC) from biologic principle of immune feedback system and data-driven principle of unfalsified control. In the IEUC, unfalsified control unit is used to select suitable controllers and immune control unit is used to adjust system performance. In order to examine the effectiveness of the IEUC, we apply it to a plant of high-speed spinning model.

This paper is organized as follows. Design of the IEUC is presented in Section 2. Then, the IEUC algorithm is presented in Section 3. We apply the IEUC to a high-speed spinning process in Section 4. Finally, summary and concluding remarks are given in Section 5.

2 Design of the Immune-Enhanced Unfalsified Controller

A novel immune-enhanced unfalsified controller (IEUC) is presented as shown in Fig. 1. The controller uses unfalsified control to evaluate preset candidate controllers and immune control to regulate control performance.

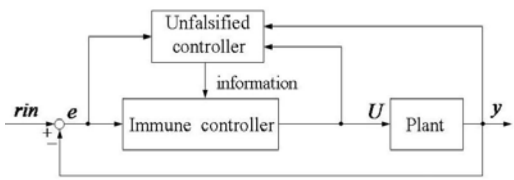

Fig. 1. The structure of the IEUC

The unfalsified control part is based on output ($yout$), control signal (U), and error (e). It transmits selected control's information to immune control part. Based on P-type immune feedback mechanism [11], the immune controller uses this information as well as error signal of system to modulate the control signal of system. In the IEUC, the unfalsified controller and immune controller can control the plant harmoniously, and hold both the advantage of data-driven methodology and biologic intelligent methodology.

For the scope of control system, the unfalsified control scheme (or the unfalsified controller, UC) is a way to build satisfactory controllers with experimental data rather than rely on feigned hypotheses or prejudicial assumptions about the plant [12]. The establishment of a qualified UC is to evaluate each candidate controller from a predefined controller set before put into feedback system which can be visually expressed as "controller sieve". Then, the "controller sieve" makes a strict evaluation of candidate controllers based on input (goal) as well as error (e). After the sieve process, candidate controllers are divided into two parts: reject controllers and accept controllers. Then, the reject controllers turn to falsified controllers as well as the accept controllers turn to unfalsified controllers. And the first unfalsified controller is selected to system loop as a current controller.

This paper builds a model based on immune feedback mechanism to adapt system control performance. The main cells involved in the model are antigen (Ag), antibody

(Ab), B cells (B), help T cells (T_H), suppressor T cells (T_s), and antigen presenting cells (APC) [11]. When Ag invades organisms, it is firstly recognized by APC. Then, the APC sends recognition message to T_H, and T_H secretes the interleukin to activate T_s and B cells. As the T_s receives stimuli, it secretes another kind of interleukin to inhibit the active of T_H. Meanwhile, as the activated B cells begin to divide, their offsprings (plasma cells) secrete Ab to recognize Ag. After a while, when Ag is prevented by Ab, a dynamic relative equilibrium point can be reached, and the immune response is finished.

3 The IEUC Algorithm

As the IEUC cannot be easily implemented without a basic control algorithm, a conventional PID control algorithm mixed with the IEUC is proposed. The basic algorithm flowchart of the IEUC is shown in Fig. 2. The left part of Fig. 2 is unfalsified control algorithm and the right part is immune control algorithm.

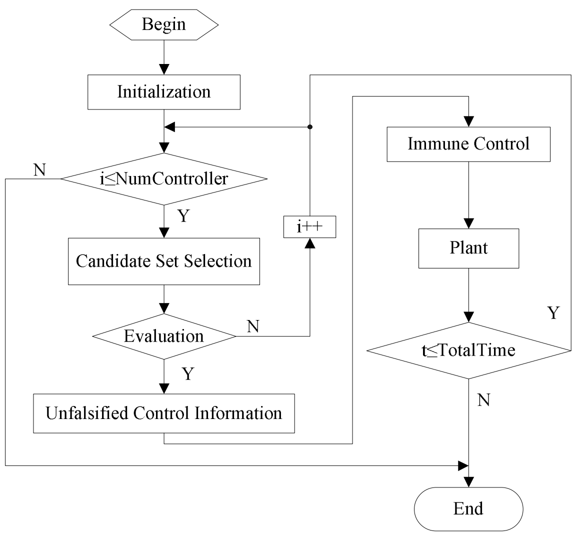

Fig. 2. The basic algorithm of the IEUC

The selection and evaluation process for the candidate set is based on the algorithm of unfalsified control [12]: $r_i(t)$ is the fictitious reference signal, combing with a basic PID-type algorithm:

$$r_i(t) = yout_i(t) + \frac{s}{s \cdot K_p + K_i} \cdot \left(U_i(t) + \frac{s \cdot K_d}{\varepsilon \cdot s + 1} \cdot yout_i(t) \right), \tag{1}$$

where i is current controller number, ε is a small enough value in PID approximate algorithm, K_p, K_i, K_d denotes proportional, integral, and derivative parameter, respectively. Performance specification set T_{spec} is

$$T_{spec}(r_i(t), yout(t), u(t)) = \left|\omega_1 * (r_i(t) - y(t))\right|^2 + \left|\omega_2 * u(t)\right|^2 - \left|r_i(t)\right|^2 , \tag{2}$$

where ω_1 and ω_2 are weighting filters depends on user's demand, $*$ denotes the convolution operator.

Moreover, performance evaluation standard E_{value} is

$$\begin{aligned} E_{value}(i, k \cdot t_s) = E_{value}(i, (k-1) \cdot t_s) + \frac{1}{2} \cdot ts \cdot \{T_{spec}\left(r_i(k \cdot t_s), y(k \cdot t_s), u(k \cdot t_s)\right) \\ +T_{spec}(r_i((k-1) \cdot t_s), y((k-1) \cdot t_s), u((k-1) \cdot t_s))\} , \end{aligned} \tag{3}$$

If $E_{value} > 0$, the current controller is falsified, the algorithm will discard the controller and continue the iteration ($i = i + 1$). Then, the UC conveys unfalsified information (K_p, K_i, K_d in this system) to immune controller. When the process comes to $i > NumController$, it means that no unfalsified controller has been found. The algorithm would terminate, and a new set of candidate controllers are required.

The immune control algorithm is as follows:

$$U(k) = \left(K_{\mathrm{P}} + K_{\mathrm{I}} \cdot \frac{1}{z-1} + K_{\mathrm{D}} \cdot \frac{z-1}{z} \right) \cdot e(k), \tag{4}$$

where,

$$\begin{cases} K_{\mathrm{P}} = K_p \cdot \{1 \text{-} \eta \cdot f(\Delta U(k))\} \\ K_{\mathrm{I}} = K_i \cdot \{1 \text{-} \eta \cdot f(\Delta U(k))\} \\ K_{\mathrm{D}} = K_d \cdot \{1 \text{-} \eta \cdot f(\Delta U(k))\} \end{cases} .$$

Where, η is a design coefficient to adjust the impact of $f(\cdot)$, $f(\cdot)$ is a nonlinear function for considering the effect of the reaction of B cells and the antigens. Also, when η =0, the IEUC controller is equal to UC controller. In this paper, the fuzzy controller with two inputs and one output is employed here to approximate $f(\cdot)$. The immune controller signal $U(k)$ and change of the controller signal $\Delta U(k)$ are two inputs variables; the output of system $yout(k)$ is the output variable. The fuzzy control rules and fuzzy functions are shown in [11].

4 Simulation Results

In order to examine the control performance of the IEUC, we consider a three-order plant in the high-speed spinning model,

$$G(s) = \frac{1.059}{0.000942s^3 + 0.3316s^2 + 1.1988s} \quad (5)$$

We set the initial parameters as, $NumController = 45$, $t_s = 0.1s$, $TotalTime$=30s, candidate controllers: $K_p = \{5,10,30,110,150\}$, $K_i = \{50,75,100\}$, $K_d = \{20,10,4\}$. Performance evaluation: $W_1(s) = \frac{s+20}{2(s+3)}$, $W_2(s) = \frac{0.01}{1.2(s+1)^3}$. Immune control parameters: $\eta = 0.6$, $l = 1$. Additionally, based on the IEUC algorithm discussed in Section 4, when $\eta = 0$, the IEUC controller is equal to UC controller.

Seen from Fig. 1, in the unfalsified control element, if the mathematical method is available, the unfalsified set of controllers can be easily obtained. However, based on Eqs. (2) and (3), as the progress of sieving, many candidate controllers could be evaluated to be falsified and rejected and it is possible that the finite set Kr of $NumController$ candidates would become empty. When the algorithm is being terminated due to this reason, argument the set Kr with additional candidate controllers or reset of the performance specification need to be done. In this case, a carefully designed set of PID parameters has been employed to act as candidate controllers and a relatively comprehensive performance specification has been adopted. In the immune fuzzy control element, by adjusting η, l in Eq. (4) and fuzzy rules, the fuzzy immune controller can quickly drive the system output to the desired level [11].

Using the IEUC, we obtain desirable control performance for the system as shown in Figs. 3 and 4. The control effectiveness is also illustrated by comparing the performance of the IEUC and the UC. In order to show the contrast effectiveness of the influence on $yout$ with rin changing, the set points of rin at the 10-th , 20-th , 30-th seconds are changed. The simulation results demonstrate that the IEUC is robust and has better control performance than that of the UC.

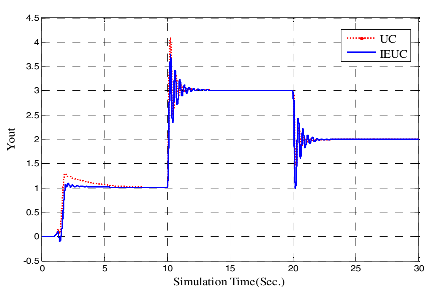

Fig. 3. The performance comparison

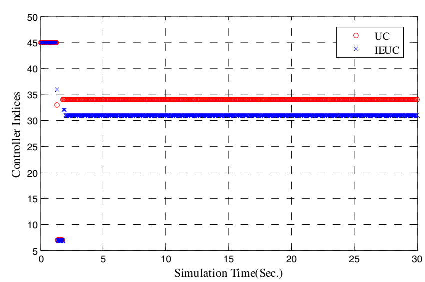

Fig. 4. The change of controller

5 Conclusions

In this paper, an immune-enhanced unfalsified controller and its control scheme are presented and applied to control a complex three-order plant in high-speed spinning model. Simulation results demonstrate that the IEUC can rapidly response to the changing of desired level. Moreover, compared with single unfalsified control algorithm, the IEUC can decrease system overshoot as well as reduce rising time easily and successfully.

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