Fixed-Structure Robust DC Motor Speed Control

Ukrit Chaiya and Somyot Kaitwanidvilai

Abstract— **This paper presents a new technique for designing a robust DC motor speed controller based on the concept of fixed-structure robust controller and a mixed sensitivity method. The uncertainty caused by the parameter changes of motor resistance, motor inductance and load are formulated as multiplicative uncertainty weight, which are used in the objective function in the design. Performance weight is designed based on the closed-loop objective which is normally applied in H_∞ optimal control. Particle Swarm Optimization (PSO) is adopted to solve the optimization problem and find the optimal controller. The proposed technique can solve the problem of complicated and high order controller of conventional H_∞ optimal control and also retains the robust performance of conventional H_∞ optimal control. Simulation results in a DC motor speed control system show the effectiveness of the proposed technique.**

Index Terms— **Fixed-Structure Robust H_∞ Control, Genetic Algorithm, H_∞ Control, DC motor speed control.**

I. Introduction

In recent years, many researchers have tried to propose an effective technique to design a controller for general plants. A more recent control technique uses computational intelligence such as genetic algorithms (GA's) or Particle Swarm Optimization (PSO) in adaptive or learning control. Karr and Gentry [1], [2] applied GA in the tuning of fuzzy logic control which was applied to a pH control process and a cart-pole balancing system. Hwang and Thomson [3] used GA's to search for optimal fuzzy control rules with prior fixed membership functions. Somyot and Manukid [4] proposed a GA based fixed structure H_∞ loop shaping control to control a pneumatic servo plant. To obtain parameters in the proposed controller, genetic algorithm is proposed to solve a specified-structure H_∞ loop shaping optimization problem. Infinity norm of transfer function from disturbances to states is subjected to be minimized via searching and evolutionary computation. The resulting optimal parameters make the system stable and also guarantee robust performance.

In DC motor speed control, many engineers attempt to design a robust controller to ensure both the stability and the performance of the system under the perturbed conditions. One of the most popular techniques is H_∞ optimal control in which the uncertainty and performance can be incorporated into the controller design. Unfortunately, the order of the resulting controller from this technique is usually higher than that of the plant, making it difficult to implement the controller in practice. In this paper, we illustrate the design of a DC motor speed controller which can guarantee stability under the specified perturbed conditions and which also has a simple structure.

This remainder of this paper is organized as follows. Section II presents the plant. Section III illustrates the proposed design. The genetic algorithm for designing a fixed structure is described in this section. Section IV shows the results. Finally, Section V concludes the paper.

II. DC Motor Modeling

A well known model of DC motor for a speed control system is shown in the following.

$$P = \frac{\omega(s)}{V_i(s)} = \frac{K}{(Ls+R)(Js+B)+K^2} \qquad (1)$$

where J (kg.m^2/s^2) is the moment of inertia of the rotor, B is the damping ratio of the mechanical system, R (ohm) is electrical resistance, L (H) is electrical inductance, and K (Nm/A) is the electromotive force constant.

According to the standard procedure of robust control [5], there are many techniques for designing a robust controller in a general plant; for example, mixed sensitivity function, mu-synthesis, H_∞ Loop Shaping, etc. However, controllers designed by these techniques result in a complicated structure and high order. The order of the controller depends on the order of both the nominal plant and the weighting functions. It is well known that a high order or complicated structure controller is not desired in practical work. To overcome this problem, a fixed-structure robust controller is designed.

III. PSO Based Fixed Structure Robust Control

PSO is used to solve the H_∞ fixed-structure control problem, which is difficult to solve analytically. The proposed technique is described as follows:

-Controller's Structure Selection

Assume that $K(p)$ is a structure-specified controller. The structure of the controller is specified before starting the PSO optimization process. In most cases, this controller has simple structures such as PID configuration or lead-lag configuration. A set of controller parameters, p, is evaluated to maximize the objective function. For example, PID with a derivative first-order filter controller can be selected.

$$K(p) = K_p + \frac{K_d s}{s+\tau_d} + \frac{K_d}{s} \qquad (2)$$

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The controller parameters set is:

$$p = [K_p, K_d, K_i, \tau_d] \tag{3}$$

-Cost function in Proposed Techniques

The cost function in the design is the infinity norm based on the concept of robust mixed-sensitivity control, which can be briefly described as follows [5].

In the mixed-sensitivity method, firstly, the weighting function of the plant's perturbation and/or performance must be specified. In this paper, W_2 is specified for the uncertainty weight of the plant and W_1 is specified for the disturbance attenuation of the system. The cost function can be written as:

$$J_{cost} = \left\| \begin{matrix} W_1 S \\ W_2 T \end{matrix} \right\|_\infty < 1 \tag{4}$$

where T is the plant's complementary sensitivity function, and S is the plant sensitivity function.

Assume that the plant is denoted as P. The controller is denoted as K and the system is the unity negative feedback control. The sensitivity and complementary sensitivity function can be expressed as:

$$S = 1 + PK \tag{5}$$

$$T = I - S = PK(1+PK)^{-1} \tag{6}$$

This cost function is based on frequency domain specifications. In this approach, the fitness value in PSO is based on the cost function in mixed sensitivity robust control. The proposed technique can be summarized as follows:

Step 1 Specify the weighting functions in robust mixed-sensitivity function [5], and the controller's structure $K(p)$. p is the unknown controller's parameters which are referred to as 'particle'.

Step 2 Initialize the several sets of p as particles in the 1st iteration of PSO. Define the PSO parameters such as population size, maximum and minimum velocities and momentum, etc.

Step 3 Generate the swarm of the first iteration randomly. Find the fitness of each particle. The inverse of the cost function in (3) is adopted as the fitness.

Step 4 Update the inertia weight (Q), position and velocity of each particle using the following equations.

$$Q = Q_{max} - \left(\frac{Q_{max} - Q_{min}}{i_{max}} \right) i \tag{7}$$

$$v_{i+1} = Qv_i + \alpha_1[\gamma_{1i}(P_b - p_i)] + \alpha_2[\gamma_{2i}(U_b - p_i)] \tag{8}$$

$$p_{i+1} = p_i + v_{i+1} \tag{9}$$

where α_1, α_2 are acceleration coefficients.

γ_{1i}, γ_{2i} are any random number in (0→1) range.

Step 5 While the current iteration is less than the maximum iteration, go to step 4. If the current iteration is the maximum iteration, then stop. The particle which has the maximum fitness is the answer of this optimization.

IV. DESIGN EXAMPLE

A speed control system is used to illustrate the effectiveness of the proposed technique. In this example, the system of the speed control of the DC motor has the parameters at the nominal plant as follows: J=0.02 kg.m^2/s^2, B=0.2 N.m.s/rad, R=2 Ω, L=0.5 H, K=0.1 Nm/A.

The specification of perturbation used for the design is shown in Table 1. As seen in the table, the reasonable tolerance and changes in system parameters are specified.

Table 1 Parameters changing in the design.

Parameter	Nominal Value	Uncertainty
J	0.02 kg.m^2/s^2	±30%
R	2 Ω	±30%
L	L=0.5 H	±30%

Performance weights can be selected properly by the well-known concept shown in [5].

$$W_1 = \frac{0.5\ s + 10}{s + 0.001} \tag{10}$$

To specify the uncertainty weight, the plots of several multiplicative plant perturbations are shown, and then the transfer function which has higher amplitude than all of uncertainty models is specified as the uncertainty weight. Fig. 1 shows the plot of set of multiplicative uncertainty models $[G(s)/G_n(s)]-1$. Where $G(s)$ is the plant and $G_n(s)$ is the nominal plant. By using mathematical software, i.e. MATLAB, the uncertainty weight can be specified [6]:

$$W_2 = \frac{(0.2619s^2 + 5.649s + 19.06)}{(s^2 + 26.28s + 106.7)} \tag{11}$$

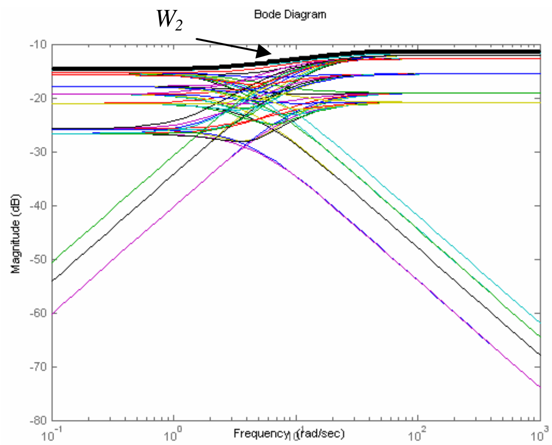

Fig.1 The design of uncertainty weight of DC motor speed control plant.

The structure of the controller is selected as PID with a derivative first order filter which has the structure as (2). The PSO parameters are selected as: population size = 50, minimum and maximum velocities are 0 and 2, acceleration coefficient = 2.1, minimum and maximum inertia weights are 0.6 and 0.9. When running the PSO for 37 iterations, an optimal solution is obtained as shown in Fig. 2.

By the proposed technique, the optimal PID with derivative first order filter controller is evaluated as follows:

$$K(p) = 92.3868 + \frac{198.9284}{s} + \frac{7.2433s}{0.0006s+1} \tag{12}$$

The infinity norm obtained by the evaluated controller is 0.533 which is less than 1. Consequently, since this norm is less than 1, then the system is robust according to the concept of mixed sensitivity robust control. A conventional mixed sensitivity controller is also designed for comparison. In the conventional technique, the order of the final controller is 4. The controller obtained by this method is

$$K(s) = \frac{135897685781.0162\,(s+21.27)\,(s+9.78)\,(s+4.085)}{(s+21.83)\,(s+0.0009994)\,(s^2+3.494e005s+6.031e010)} \tag{13}$$

Cleary, the order of the conventional technique controller is high and its structure is very complicated. Thus, the advantage of simple structure can be obtained by the proposed technique. The step responses of both proposed and conventional technique at nominal conditions are shown in Fig. 3. This figure shows that the settling time from the proposed controller is almost the same as the conventional robust controller while overshoot does not appear.

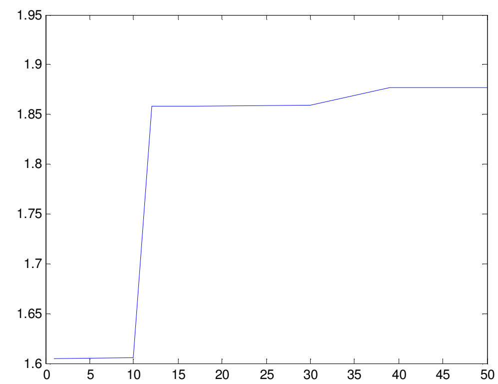

Fig.2 Convergence of solution of the proposed technique.

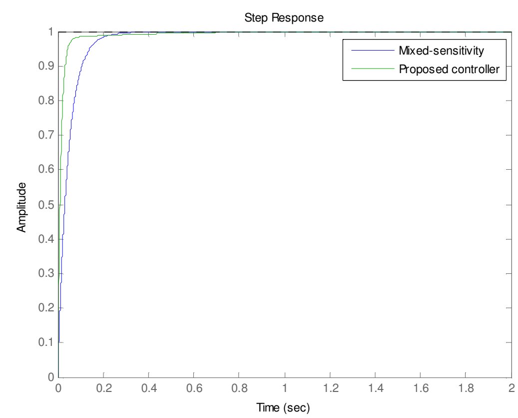

Fig. 3 Step responses of the proposed optimal PID controller and a conventional robust controller at a nominal plant.

To verify the effectiveness of the proposed controller, the system with plant perturbation is examined. In this case, the parameters of the system are changed to: J=0.014 kg.m^2/s^2, B=0.2 N.m.s/rad, R=1.6 Ω, L=0.35 H, K=0.1 Nm/A. Step responses of both proposed and conventional technique at the perturbed plant are shown in Fig. 4. As seen in this figure, the settling time of the proposed controller is almost the same as in the conventional robust controller, and the responses are similar to that of the nominal plant. Cleary, both the proposed and conventional controllers are robust.

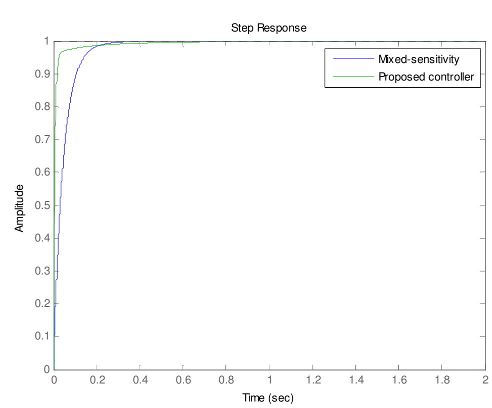

Fig.4 Step responses of the proposed optimal PID controller and a conventional robust controller at a perturbed plant.

V. Conclusions

The proposed technique can be applied to control the speed of a DC motor. Based on the incorporation of robust control and the PSO concepts, the proposed technique can achieve robustness and good performance while the structure of the controller is simple. Robustness of the controlled system can be guaranteed via the theory of mixed sensitivity robust control.

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