

2DOF H infinity Control for DC Motor Using Genetic Algorithms

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Abstract—This paper presents a new method of 2DOF H infinity Control for DC Motor. The proposed technique applies the Genetic Algorithms to achieve the specified structure robust control design. The robustness in terms of robust 2DOF control is achieved by the proposed design and the control results are compared with the conventional 2DOF H infinity control. As results indicated, the proposed method is simpler and the order of the proposed controller is lower than that of the conventional robust control technique. The comparison is done by performing the simulation using the transfer function of the real motor system.

Index Terms—2DOF H infinity Control, DC motor system, genetic algorithm

I. INTRODUCTION

Both 2DOF control and robust control can be incorporated to design a robust controller to achieve both time and frequency domain specifications. The technique, called 2 DOF H infinity control is widely used to design the robust control with the time domain specification. However, similar to the robust control techniques, the structure of the resulting controller is normally complicated with high order. In this paper, we propose the design control technique using 2DOF H infinity control and Genetic Algorithms to the DC motor speed control. Many researchers proposed the control techniques for speed control of the motor. Hwu and Liaw [1] studied the speed control of the switch reluctance motor. In their paper, they found that the dynamic system can be approximated but hardly to be accomplished. Lee and Schmidt [2] applied the control method for controlling an uncertainty system and an external disturbance which was examined in the high sensitive system called “seeker scan loop system”. Additionally, they summarized that the 2DOF control is better than the 1DOF control.

Knittel et al [3] presented that the 2DOF H infinity Control can hold the tension control which is disturbed by the adding load torque. Owing to torque load increased, a spool drive was vibrating while operating. The 2DOF H infinity control is able to reduce the vibration in this problem. Harnefors et al [4] adopted the 2DOF H infinity Control for controlling a permanent magnet servo motor which was driven by field oriented control. The results in this paper

showed that the 2DOF H infinity control can not only decrease the un-modeled dynamics, but also better perform the response than that of the 1DOF H infinity control.

The outline of the article is as follows. Section II consists of the theory of 2DOF H infinity control, the output error system identification, and the new technique of 2DOF H infinity Control for DC Motor using Genetic Algorithms. Section III presents the design of the proposed controller using the 2DOF H infinity Control for DC Motor using Genetic Algorithm. Simulation results are shown and discussed in this section. Finally, the last section concludes the research work and illustrate the discussion.

II. 2DOF H INFINITY CONTROL, SYSTEM IDENTIFICATION AND THE PROPOSED TECHNIQUE

A. System Identification

Standard system identification can be performed to determine the parameters of the dynamic model from the measured data in any systems. The measured data derived from the input and output system are used to the identification process. In this paper, the OE (Output Error) method [5] is selected as the linear model of DC motor.

Bringing the measured data and the number of poles (n_p) with zero plus one (n_b) of system and delay(n_k), the black box model identification process can be performed. The results of this process are the model parameters, i.e. f_1, f_2, \dots, f_{n_f} and b_1, b_2, \dots, b_{n_b} . The transfer function of the system is as the following equation.

$$G(s) = \frac{B(s)}{F(s)} = \frac{b_{n_b}s^{(n_b-1)} + b_{n_b-1}s^{(n_b-2)} + \dots + b_1}{s^{n_f} + f_{n_f}s^{(n_f-1)} + \dots + f_1} \quad (1)$$

Fig. 1 shows the diagram of the OE model.

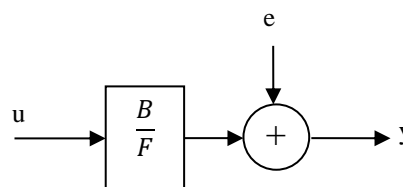


Fig. 1 Diagram of the OE model

B. 2DOF H infinity control

2DOF H infinity control is a method which is able to specify the time domain specification into the H infinity robust control. Normally, H infinity control specifies the specifications in the frequency domain. The 2DOF H infinity control consists of a feed-forward pre-filter controller, K_1 , and a feedback controller, K_2 . K_1 is used for controlling the response of time domain of the closed loop system; in addition, K_2 is designed for achieving the robust performance and disturbed reduction of the entire system. The 2DOF H

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infinity control uses only one weighting function which is the pre-compensator weight function, W_I to specify the loop shape. In addition, the reference model, T_{ref} is applied to establish the time domain specification. Considering the shaped system (G_s) which can be formulated as co-prime factors [6] which consists of the nominator factor: N_s and the denominator factor: M_s . Fig. 2 demonstrates the uncertainty model of the system and robust control synthesized systems.

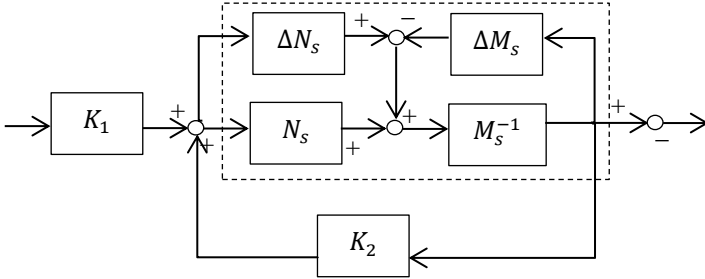


Fig. 2 uncertainty system of co-prime factors

When T_{ref} is used for referring the model of the time domain specification.

ρ is a constant which is designed to monitor the well performance of the control system. Loop shaping system can be described in the following equation:

$$G_s = GW_I = M_s^{-1} N_s \quad (2)$$

Equation (2) combines the uncertainty into the shaped system.

$$G_\Delta = (N_s + \Delta N_s)(M_s + \Delta M_s)^{-1} \quad (3)$$

G_Δ is uncertain system.

ΔN_s is uncertain transfer function of the nominator.

ΔM_s is the uncertain transfer function of the denominator.

$$|\Delta N_s, \Delta M_s|_\infty \leq \varepsilon \quad (4)$$

ε is stability margin.

The followings are the steps of the conventional design procedure of the 2 DOF H infinity control.

Step 1 Pre-compensator weight function (W_I) is designed to perform an open loop shaping

Step 2 Reference model (T_{ref}) is designed to refer the time domain specification of the closed loop system, and to use ρ to select the performance and efficiency of time and frequency domains. ρ has ranged from 0 to 1. If the designer selects $\rho = 0$, the 2DOF H infinity control becomes the 1 DOF H infinity control.

Step 3 ε_{opt} is determined by solving the following equation (5).

$$\gamma_{opt} \rho^{-2} = \varepsilon_{opt}^{-1} \rho^{-2} = |(I - G_s K_2)^{-1} G_s K_1 - T_{ref}|_\infty \quad (5)$$

Step 4 After step 3, the K_I and K_2 are synthesized [7] by solving the following inequation.

$$\|T_{ZW}\|_\infty = \left\| \begin{bmatrix} \rho(I - K_2 G_s)^{-1} K_1 & K_2 (I - G_s K_2)^{-1} M_s^{-1} \\ \rho(I - G_s K_2)^{-1} G_s K_1 & (I - G_s K_2)^{-1} M_s^{-1} \\ \rho^2 [(I - G_s K_2)^{-1} G_s K_1 - T_{ref}] & \rho(I - G_s K_2)^{-1} M_s^{-1} \end{bmatrix} \right\|_\infty \leq \varepsilon^{-1} \quad (6)$$

Step 5 W_I is synthesized by:

$$W_I = [W_0 (I - G_s(0) K_2(0))^{-1} G_s(0) K_1(0)]^{-1} T_{ref}(0) \quad (7)$$

By $W_0 = 1$

Step 6 K_I and K_2 is tested to ensure the performance of the designed system.

The resulting controller obtained from the above mentioned procedure has high order. If the order of the controller is high, it is difficult to be implemented in real system. To overcome this problem, in the proposed technique, the design of the structure of the controllers K_I and K_2 is firstly selected and then the genetic algorithms are adopted to compute the control parameters of K_I and K_2 to achieve the maximum stability margin in (6). Generally, the controller is shown in Fig. 3 for real implementation.

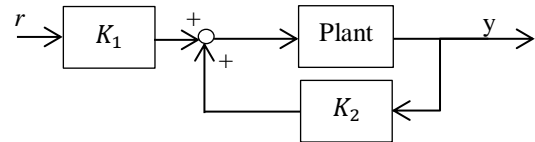


Fig. 3 2DOF control

To summarize the proposed design, the following steps of the proposed technique are described.

Step 1 T_{ref} and W_I are selected to achieve both desired loop shape and time domain response. Also, the structures of the controllers K_I and K_2 are selected. In this paper, we selected the structures as:

$$K_1 = \frac{1}{K_f s + 1} \quad (8)$$

$$K_2 = K_p + \frac{K_i}{s} + K_d s \quad (9)$$

Step 2 Genetic algorithm is applied for determining the parameters in K_I and K_2 so that the maximum stability margin can be achieved.

$$\|T_{ZW}\|_\infty = \left\| \begin{bmatrix} \rho(I - K_2 G_s)^{-1} K_1 & K_2 (I - G_s K_2)^{-1} M_s^{-1} \\ \rho(I - G_s K_2)^{-1} G_s K_1 & (I - G_s K_2)^{-1} M_s^{-1} \\ \rho^2 [(I - G_s K_2)^{-1} G_s K_1 - T_{ref}] & \rho(I - G_s K_2)^{-1} M_s^{-1} \end{bmatrix} \right\|_\infty \quad (10)$$

By $K_{2\infty} = W_1^{-1} K_2(p_2)$

Step 3 System performance of the proposed controller is tested.

III. DC MOTOR SYSTEM AND SYSTEM IDENTIFICATION

The DC motor system is designed to create the single axis driving with DC motor. The lead screw changes from the radial motion to linear motion. The angular velocity is measured by the encoder joined at the end of the lead screw. DC motor is driven by H-bridge circuit, and PWM signal is

made from a microcontroller, “ARM Cortex-M4 processor” to transfer the data for feedback control.

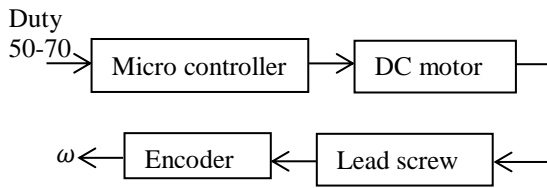


Fig. 4 Diagram of DC motor system

The system identification technique was performed to determine the parameters of the dynamic model of DC motor from the measured data. The measured data derived from the input duty cycle shown in Fig. 5, and the speed output shown in Fig. 6. OE (Output Error) method is used for modeling the Linear model of DC motor. This model is created by selecting the identification parameter as $n_b = 2$, $n_f = 2$, $n_k = 1$.

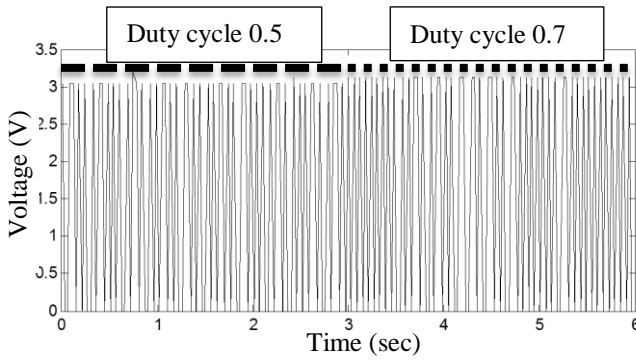


Fig. 5 Input signal of system (Voltage)

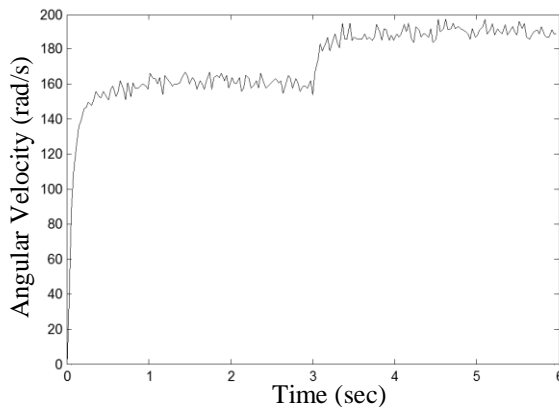


Fig. 6 Output signal of system (Speed)

TABLE I. Transfer function derived from system identification

Duty cycle(%)	Transfer function
50-70	$B(s) = 8.92 \times 10^3 s + 6.152 \times 10^9$ $F(s) = s^2 + 7.106 \times 10^7 s + 4.746 \times 10^8$
60-80	$B(s) = 9.15 \times 10^3 s + 5.291 \times 10^9$ $F(s) = s^2 + 4.519 \times 10^7 s + 3.293 \times 10^8$

IV. EXPERIMENTAL AND SIMULATION RESULTS

This experimental setup adopted in this paper for the system identification is shown in Fig. 4. When applying the proper signal to the system, the measured data needed for the identification can be achieved. Then the identified model was used to the controller design. The identified plants are

shown in TABLE I. The designed plant is the plant at the operating point (duty 50%-70%) and the other plant with duty cycle 60-80% is used to verify the robustness when the plant is changed. The conventional H infinity 2DOF control and the 2DOF H infinity control using genetic algorithm are tested in the system by applying the step response. The performance and robustness in terms of the rise time, overshoot, settling time, bandwidth, and stability margin of the proposed algorithm are investigated in comparison with the conventional control.

In the conventional technique, the weight and reference model were selected as:

$$W_1 = \frac{99.52s+1659}{s+0.001} \quad (11)$$

$$T_{ref} = \frac{1}{0.0384s+1} \quad (12)$$

The selected W_1 results in the optimal stability margin $\epsilon_{opt} > 0.25$ and the T_{ref} results in the satisfied settling time.

Then, the K_1 and K_2 were synthesized using the conventional technique as the filters with 4th order.

$$K_1(p) = \frac{2987s^3+1.351e11s^2+1.575e15s+2.622e16}{s^4+4.944e07s^3+1.81e14s^2+7.729e15s+7.855e16} \quad (13)$$

$$K_2(p) = \frac{-4.078e06s^3-1.842e14s^2-7.863e15s-7.986e16}{s^4+4.944e07s^3+1.81e14s^2+7.729e15s+7.855e16} \quad (14)$$

The designed controller by the proposed technique using genetic algorithms was evaluated. The structures of controllers in (8) and (9) were selected. After running the GA for 95 generations, the optimal control parameters, $K_f=1000.9$, $K_p=31.0035$, $K_i=1694.2$, and $K_d=0.492$ were obtained for K_1 and K_2 .

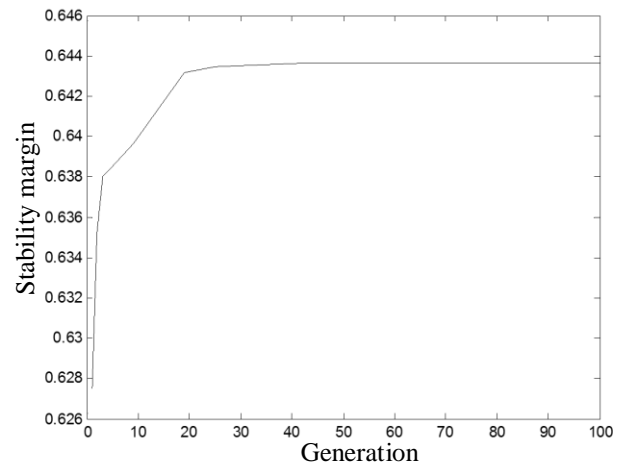


Fig. 7 Stability margin versus generations obtained from the genetic algorithms

The equations (11), (13), and (14) are the weight function and the conventional 2DOF robust controller. As comparison with the proposed controller evolved by GA, the order of the proposed controller is low which is easy to be implemented in practical system.

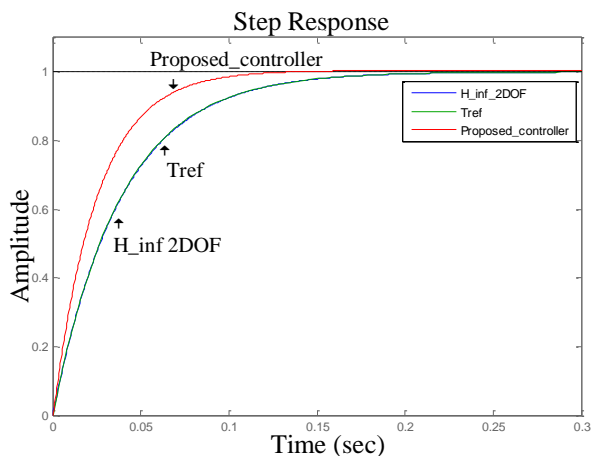


Fig. 8 Step response of the closed loop system from various controllers

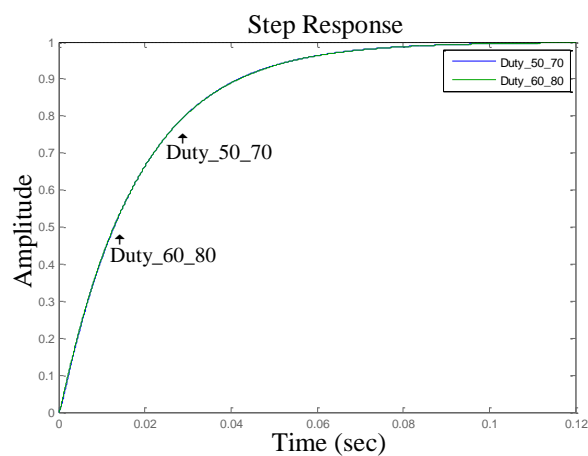


Fig. 10 The robustness of the system is tested by the step response in other operating points.

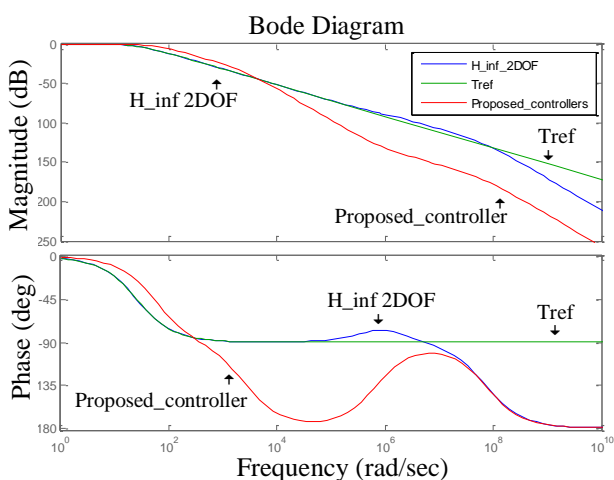


Fig. 9 Bode diagrams of the closed loop system from various controllers

The time domain performance of various controllers is compared as shown in TABLE II.

TABLE II. The comparison of the DC motor control system with various controllers.

	Step responses result				
	Rise time	Bandwidth	Settling time	Over shoot	Stability margin
H _{inf} 2DOF GA	0.0536	55.3986	0.0927	0	0.6436
H _{inf} 2DOF	0.0848	25.8496	0.151	0	0.6422
T _{ref}	0.0844	-	0.15	0	-

The result of simulation shows that the identified transfer functions of Output Error system identification are moderate because the studied system is nonlinear system, but the Output Error system model is suitable for the linear system. The step responses of the proposed controller and the H infinity 2DOF control are investigated in the simulation results. As seen in the results in Figs. 8 and 9, the rise time and settling time of the proposed controller is less than the H infinity 2DOF control and the bandwidth of the proposed controller is near the H infinity 2DOF control. In addition, the stability and performance of the proposed controller is similar to the H infinity 2DOF control while the order of the proposed controller is much lower than that of the conventional technique.

Simulation results shown in Fig. 10 of the changing plants from the designed plant (duty 50%-70%) and the other plant (duty 60%-80%) of the proposed controller shows that the proposed system is robust. The response is similar to the original design even the plant is changed.

V. CONCLUSIONS

This paper proposes the new technique of H infinity 2DOF control using genetic algorithm which is used to search the parameters of controller in fixed structure fashion. The performance of the proposed controller is nearly the same as the conventional H infinity 2DOF control achieved by the synthesis of mathematics. However, the conventional robust 2DOF control is hardly to be used in the practical system because K_1 and K_2 are normally high order controller. In contrary, the order of the proposed controller is lower, and the proposed system still retains the good performance and robustness. The stability margin verifies the effectiveness of the proposed algorithm. As seen in frequency domain plots and time domain responses, the proposed technique is a promising technique which can be applied to the DC motor system.

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