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Joint Control Method Based on Internal Structure of 2DOF Control System

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Abstract

Recently, 2DOF control system has been widely recognized to be efficient. The major merit of 2DOF control is the independency between tracking performance and feedback performance. But the design of two parameters of 2DOF control system is not much considered about the relation between the identification and the design. In the field of robust control, the joint control, which can combine the identification with the design, is investigated. Then we apply the joint control to the design of 2DOF control system, and verify the effectiveness by some simulations.

1. Introduction

Recently, 2DOF control system has been widely recognized to be efficient. The major merit of 2DOF control system is the independency between tracking performance and feedback performance. By the analysis of the internal structure of 2DOF control system using coprime factorization, we have shown that the design problem of 2DOF control system is equivalent to the design of two parameters, K and Q [2] . The parameter K is a part of the feedforward controller and specifies nominal tracking performance. By giving the desired model for tracking performance, the parameter K is easily determined according to the model matching problem. The parameter Q constructs the feedback controller and specifies feedback performance such as robust stability and robust performance. Since not only Q but also the plant variation R determines robustness of the control system, the design of Q and the identification of R are not considered separately. Then we propose the joint control method of 2DOF control system combining the design of Q and the identification of R. Due to this combination, we expect the improvement of robustness of the control system. The effectiveness of the proposed method is verified by some simulations.

2. 2DOF control system

In this section, we review the internal structure of 2DOF control system briefly. By using coprime factorization, the controlled plant P and its mathematical model P_0 can be represented as

$$P = ND^{-1} ,P_0 = N_0 D_0^{-1} \quad (N, N_0, D, D_0 \in RH_\infty) \tag{1}$$

follows.

Assuming that P_0 is stabilizable by a state feedback, there can be a controller C which is capable of stabilizing P_0, and its class is described as eq. (2) with a free parameter Q and coprime factorization of P_0:

$$C = (Y_0 - QN_0)^{-1}(X_0 + QD_0) \quad (X_0, Y_0, Q \in RH_\infty) \tag{2}$$

where X_0 and Y_0 are one solution that fulfills

$$X_0 N_0 + Y_0 D_0 = 1. \tag{3}$$

Assume that the actual controlled plant P is stabilized by C. This assumption has few constraints on practice. Then P can be expressed as follows due to the symmetry of the Youla parameterization:

$$P = (N_0 + Y_0 R)(D_0 - RX_0)^{-1} \quad (R \in RH_\infty) \tag{4}$$

Fig.1 shows a block diagram of a 2DOF control system. In Fig. 1, r, u, and y are the reference input, the control input, and the measured output respectively, β and ξ are the internal signal of control system. K is a free parameter specifying tracking performance. In case that there is no variation between P and P_0, tracking performance of the control system is described as N_0K, the measured output y is equal to N_0Kr. An equivalent variation of Fig.1 can be introduced by substituting eq. (4) into Fig. 1. Fig.2 shows

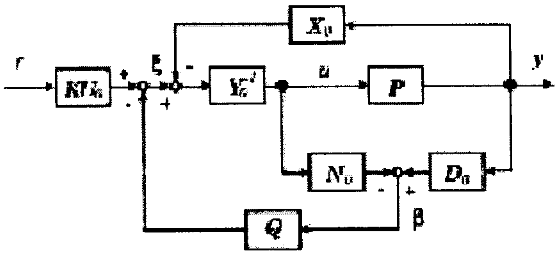

Fig. 1 Internal structure of 2DOF control system I

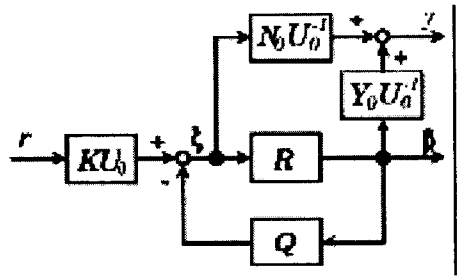

Fig. 2 Internal structure of 2DOF control system II

that the variation R can be identified from β and ξ and robust stability condition is induced from small gain theorem as follows:

$$(1+RQ)^{-1} \in RH_\infty \tag{5}$$

From the above statement, it is clear that all characteristics of a 2DOF control system are specified by two free parameters such as K and Q, designing a 2DOF control system is equivalent to designing K and Q. The free parameter K associated with tracking performance can be determined by solving a model matching problem. And the free parameter Q specifying feedback performance can be tuned while satisfying the robust stability condition (5). Then we propose the new design method of 2DOF control system that R and Q is treated as the controlled plant and the controller to be designed respectively by using the joint control.

3. Joint control design

In this section, the design method of 2DOF control system taking into account the interaction between the design of Q and the identification of R is stated. We adopted a trajectory control of D.D. manipulator, which is an unstable plant, as a concrete application of 2DOF control system. Here, the mathematical model of the controlled plant P_0 is given as eq. (6).

$$P_0 = N_0 D_0^{-1} = \frac{K_t}{(Js+D)(\tau_0 s+1)} \bullet \left(\frac{s}{\tau_0 s+1}\right)^{-1} \tag{6}$$

In this equation, N_0 and D_0 are the coprime factorization of P_0, K_t is a torque constant, and J and D represent inertia and viscous resistance of a manipulator respectively. τ_0 is a time constant of a filter using in coprime factorization. A PD controller, which is known to be efficient for position control, is adopted as a nominal controller $X_0 Y_0^{-1}$ which stabilize P_0.

$$X_0 Y_0^{-1} = 1 \bullet \left\{\frac{(\tau_1 K_p + K_d)s + K_p}{\tau_1 s+1}\right\}^{-1} \tag{7}$$

K_p and K_d denote a proportional and a differential gain respectively. In order to take into account implementation on DSP, differential control is approximated by using a high-pass filter with a small time constant τ_1. The global control object is set to minimization of the tracking error associated with 2-norm. Then the control criterion in frequency domain J is determined as eq. (8) with a transfer function from r to y denoted by G_{yr} and a model transfer function G_M associated with tracking performance.

$$J = \left\| G_M - G_{yr} \right\|_2 \tag{8}$$

Since obtaining the optimal controller Q and the variation R such that minimize J is a simultaneous optimization problem associated with Q and R, it is difficult to solve this problem generally. Then, the control criterion J is divided into two criteria denoted by J_1 and J_2 by using a triangle inequality[1].

$$J \le J_1 + J_2$$
$$J_1 = \left\| G_M - \tilde{G}_{yr} \right\|_2 \quad J_2 = \left\| \tilde{G}_{yr} - G_{yr} \right\|_2 \tag{9}$$

J_1 and J_2 are considered as the criterion of designing Q and of identifying R respectively. J_1 is considered to be nearly equal to J since the identification of R makes minimize J_2. And the design of Q leads, namely minimization of J_1, to minimize J which should be minimized originally.

4. Design procedure of 2DOF control system

In this section, the design procedure of 2DOF control system is stated in detailed.

STEP 1

Design K which specifies tracking performance

$$K = G_M N_0^{-1} \tag{10}$$

by solving model matching problem.

Note that the order of G_M is limited to make K proper.

STEP 2

Identify R based on the prediction error method in open loop case ($Q = 0$) and name it R_0.

$$R_0 = \arg\min_{\tilde{R}} \left\| \beta - \tilde{R}\xi \right\|_2 \tag{11}$$

Set the trial number to be 1.

STEP 3

Design Q_i using identified R_{i-1}. Here, each index represents the trial number.

$$\begin{aligned} Q_i &= \arg\min_{\tilde{Q}} \left\| G_M - \tilde{G}_{yr} \right\|_2 \\ &= \arg\min_{\tilde{Q}} \left\| \frac{(Y_0 - \tilde{Q})R_{i-1}K}{1 + \tilde{Q}R_{i-1}} \right\|_2 \end{aligned} \tag{12}$$

STEP 4

Identify R_i using designed Q_i in the previous step.

$$\begin{aligned} R_i &= \arg\min_{\tilde{R}} \left\| G_{yr} - \tilde{G}_{yr} \right\|_2 \\ &= \arg\min_{\tilde{R}} \left\| F_i \frac{K}{1 + Q_i R}(R - \tilde{R}) \right\|_2 \end{aligned} \tag{13}$$

$$F_i = \frac{Y_0 - N_0 Q_i}{(1 + Q_i R_{i-1})U_0} \tag{14}$$

STEP 5

If the value of J hardly changes in comparison with the previous value of J, set the current R_i and Q_i to R and Q , then finish the design of 2DOF control system. If not so, set the trial number to be $i + 1$ and return to STEP 3.

Since R_{i-1} is used instead of R_i , this algorithm needs iterative operation such as STEP 5 naturally. It is clear from eqs. (13) and (14) that the identification of R and the design of Q are associated by the similar filter. This leads to improve control performance in comparison with the conventional design method ignoring the interconnection between the identification and the design.

5. Simulation result

In this section, we show simulation results to verify the effectiveness of the proposed design

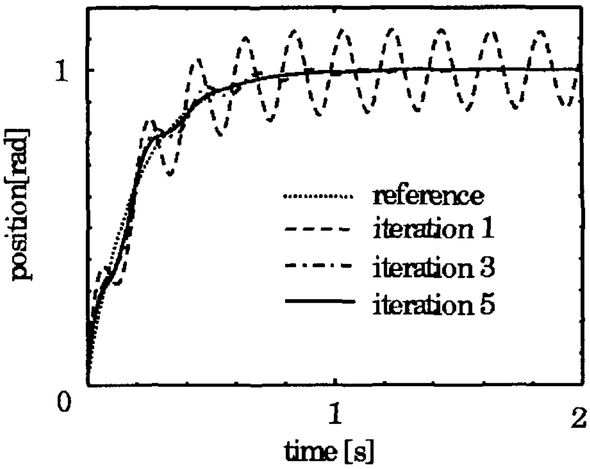

Fig. 3 Step response

method. Fig.3 shows the step response. From Fig. 3, oscillation is suppressed and the measured output approaches the desired trajectory as the trial number increases.

6. Conclusion

In this paper, we proposed the new design method of 2DOF control system taking into account the joint control. We have confirmed that the proposed method can achieve higher performance.

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