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Robust Position Control of Rigid and Flexible Manipulator Using P-IP Controller and Speed Error Based Controller

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1. Introduction

In position control of DC motor, commonly composes of position controller and speed controller. Here, I try to improve the robustness and performance of position control using an improved model of standard speed controller.

2. Speed Error Based Controller (SE-BC)

Recently, a new type of Disturbance observer was proposed, and it was named Error based Disturbance Observer [1]. This system used position error as its input to the observer.

In this paper I proposed a new controller to improve system robustness; I call it as a Speed Error Based Controller (SE-BC). The general structure of the proposed controller is shown in Fig. 1, where this controller is implemented in speed loop and uses two controller Ga(s) and Gb(s).

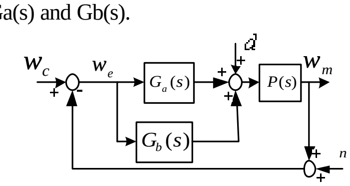

Fig. 1. General structure of SE-BC

Here, the parameter for Ga(s) and Gb(s) are designed extended the idea of Error Based Disturbance Observer and transform it into a general form. The parameters of both controllers are as follows,

$$G_a(s) = \frac{C(s)}{1 - Q(s)} \qquad (1)$$

$$G_b(s) = \frac{Q(s)}{P_n(s)(1 - Q(s))} \qquad (2)$$

Fig.2 shows more detail of the SE-BC structure with C(s), d, P(s), Pn(s), w_e, w_m, w_c, n are controller, disturbance, plant, nominal plant, speed error, speed of motor, command speed and noise.

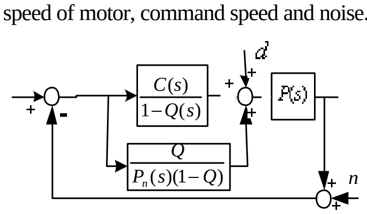

Fig 2. Structure of SE-BC system

From the block diagram of Fig 2, we can obtain the following transfer functions

$$G_1(s) = \frac{w_m}{d} = \frac{P(s)P_n(s)(1-Q(s))}{Pn(s)(1-Q(s)) + (P_nC(s)+Q)P(s)} \qquad (3)$$

$$G_2(s) = \frac{w_m}{w_c} = \frac{(P_nC(s)+Q)P(s)}{Pn(s)(1-Q(s)) + (P_nC(s)+Q)P(s)} \qquad (4)$$

Here, since the disturbance suppression is more important in lower frequency range, here we design the low pass filter Q(s) as a low pass filter with unity dc gain. And because the plant is a first order system, thus we can implement a first order Q(s) filter as follows:

$$Q(s) = \frac{1}{ts+1} = \frac{g}{s+g} \qquad (5)$$

With t is the filter time constant and g as filter bandwidth.

Thus for low frequency, Q(s) = 1, the value of $G_1(s)=0$. This shows disturbance is rejected completely. Also substitutes the low pass filter Q(s) into eq. (3), we obtain

$$\frac{w_m}{d} = \frac{tsP(s)P_n(s)}{tsPn(s)(1-Q(s)) + (ts+1)(P_nC(s)+Q)P(s)} \qquad (6)$$

This means, that the smaller time filter constant makes the disturbance attenuation property better. And from bode plot of eq. (6) in Figure 3, we can see that the smaller time constant of Q(s) makes disturbance attenuation property of SE-BC improved. Thus increasing cutoff frequency g would increase robustness of servo control against torque disturbance and parameter variation.

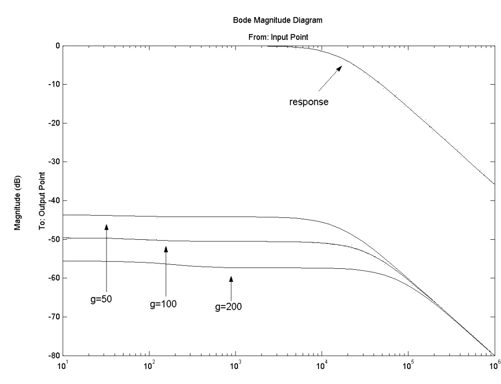

Fig 3. Bode plot of eq. (6)

And also when Q(s) = 1, $G_2(s) = 1$, this shows at low frequency, the speed closed loop transfer function ideally close to one, as shown in bode plot of Fig. 4, This is because SE-BC inherently has a feedforward of inverse dynamic plant. This feedforward term acts as a dynamic compensation which makes actuator easy to follow the track, and improve tracking performance in the closed speed loop.

3. Position control of rigid manipulator

The proposed position control system for rigid manipulator is shown in Fig. 5, which is basically P-IP (Proportional plus Integral-Proportional) controller with SE-BC.

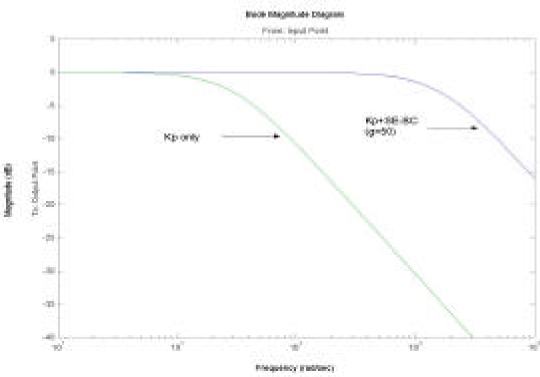

Fig 4. Bode plot of eq. (4)

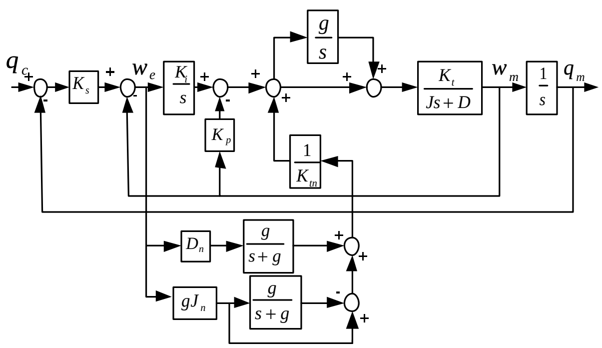

Fig 5. Proposed position control for rigid manipulator

Figure 6 shows the experimental result of rigid manipulator which shows the overshoot response of P-IP and combining P-IP controller with SE-BC in position control of rigid manipulator will improve the robustness of the system against arm load variation and other disturbance.

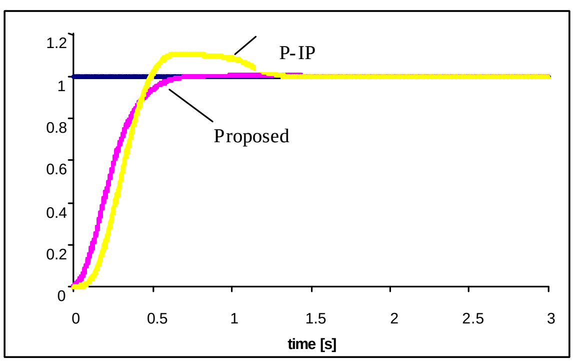

Fig 6. Step response for rigid manipulator

4. Position control of flexible manipulator

For flexible manipulator, we modeled the plant as two mass model The transfer function from the motor torque to the motor's angle can be expressed as follows:

$$G_m(s) = \frac{q_m(s)}{T_m(s)} = \frac{s^2 + w_a{}^2}{J_m s^2 (s^2 + w_m{}^2)} \qquad (7)$$

where, wa and wm are the anti-resonance and resonance frequencies, respectively. Fig. 7 show the proposed position control of flexible manipulator using P-IP controller with SE-BC and adding speed feedback gain *Kv* to improve damping of the position control system . Here, Kv is set to obtain optimum damping as shown in root locus Figure of Fig. 8.

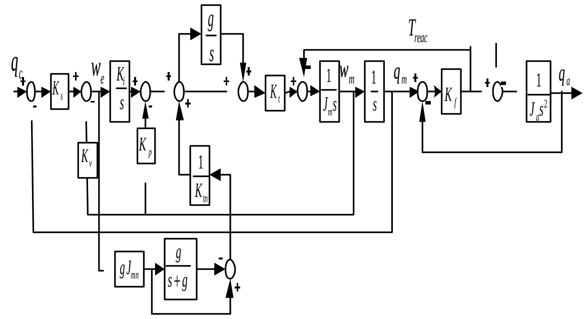

Fig 7. Position Control of Flexible Manipulator

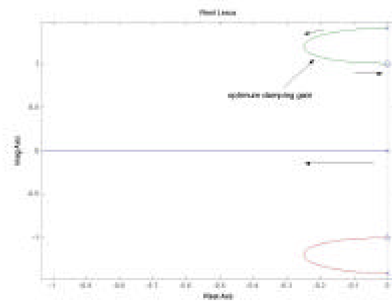

Fig 8. Root locus of Kv

Figure 9 shows the experimental result of the proposed control system and compare it with response from PD system, this show robustness of the proposed method.

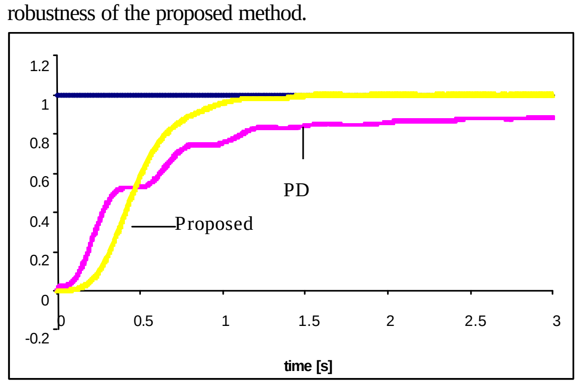

Fig 9. Step response for rigid manipulator

5. Conclusion

I proposed a new controller to improve system robustness; we call it as a Speed Error based Controller (SE-BC). This controller has disturbance suppression property which dependent on the low pass filter's cut-off frequency *g*. And using SE-BC has inherently a feedforward for dynamic compensation of plant in the speed loop. loop Thus these mean using SE-BC the system will have disturbance suppression, compensation of inertia variation and friction, all in the speed closed loop part of the position control system.

Finally, I developed a position control using P-IP controller and SE-BC to obtain robust position control with no overshoot and steady state error for step input command.

6. Reference

[1] K.Yang . "Robust Tracking control of ODD systems using Error based Disturbance Observer Proc. ACC`02,2002.