High Shock Disturbance Rejection of Single-Link Robot Arm with a Disturbance Observer

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Abstract

In this paper, we propose a disturbance observer system for an instrument that is affected by regular shock. The disturbance observer uses the position error signal and a nominal model of the plant to create an estimation of the disturbance. The disturbance observer algorithm is designed to enforce robust input/output behavior by canceling the effects of disturbances and modeling errors. We apply to the filter using the binomial filter design method. The design of disturbance observer using the methods improves the performance of disturbance rejection. The effectiveness of the disturbance observer in rejecting high shock disturbances is demonstrated in simulation.

1 Introduction

Recently, robot motion control has been the important technology. It has been expected that robots help us, human beings, or that robots work in various fields instead of us. Especially, robots have been expected to work in the heavy environment where human beings can not stand, or to be active in the medical and welfare fields. In order to respond to the above expectations, teleoperation has been researched as one of the robot motion control methods[1].

Position controller is one of the important parts in robot motion control system. It mainly functions to accept command signals from the process control computer and feed-back signals from load, and output control signals to motor velocity control system so as to drive the mechanical transmission to ensure that the load tracks its target timely and precisely. It remains as a hard nut many people are trying to crack that restrict requirements are placed on input signal smoothing, motional disturbance, and system precisition, stability and quick response, as well the parameters are difficult to mach with each other. The currently available position controls mostly adopt PID control mode. PID control is effective for simple process control but limited for the targets whose parameters vary in large range or are remarkably non-linear[3]. To meet these advanced requirements, various kinds of controllers have been proposed. Disturbance observer is adaptive robust controller.

In this paper, we propose a disturbance observer system for an instrument that is affected by regular shock. The regular disturbances cause a position error of the machine. Research about reducing the position error by the disturbance has been made progress. But, it is insensibility to high shock regular vibration. So we research possible to implement a disturbance observer (DOB) in the systems that has high shock regular vibration.

This research suggest a disturbance observer for position control of a BLDC motor that is used to position control of a single-link robot arm. The system model of the motor is calculated using ADAMS. And, the parameters of the disturbance signals are 9000N of high shock and 11Hz of regular shock. Fig. 1 show disturbance signal.

2 Selection of Disturbance Observer

Among these kinds of robust motion control methods with two-loop structure, it can be said that the most popular method is the disturbance-observer (DOB)-based control. The disturbance observer uses

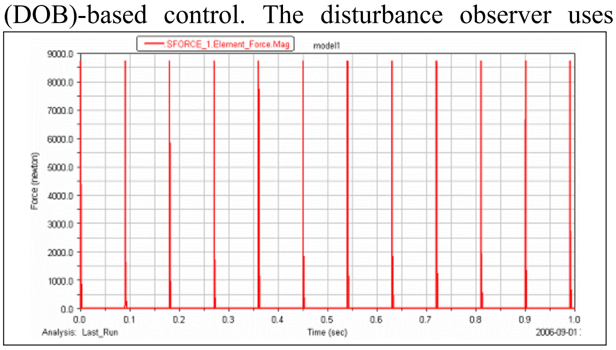


Fig.1 Disturbance

the position error signal and a nominal model of the plant to create an estimation of the disturbance. The estimation is then used to compensate for the disturbance effects.

Using the low-pass filter $Q(s)$ and the inverse of a nominal model, the DOB estimates the disturbance and the estimate signal is utilized as a disturbance cancellation input. Hence, the DOB makes the system's behavior between control input and plant output robust in the presence of uncertainties and disturbances. Fig. 2 shows the structure of the DOB. From the block diagram in Fig. 2, the plant $P(s)$ output y can be expressed in terms of the reference control input u_r, the external disturbance d_{ex}, and the measurement noise ξ

$$y = [P_n(s)u_r + P_n(s)1 - Q(s)d_{ex} - Q(s)\xi]\frac{P(s)}{X(s)} \qquad (1)$$

where, $X(s) = P_n(s) + [P(s) - P_n(s)]Q(s)$, nominal model $P_n(s)$ of DOB. Below the cutoff frequency of $Q(s)$, $|Q(jw)| \approx 1$ is achieved. Hence, low-frequency disturbances are attenuated and the mismatch between the plant $P(s)$ and the nominal model $P_n(s)$ is compensated. Thus, the behavior of the real plant is to be the same as the given nominal model. On the other hand, $|Q(jw)| = 0$ is achieved above the cutoff frequency of $Q(s)$. Hence, high-frequency measurement noise is attenuated. As a result, the following observations come to light. Firstly, the most important design parameter in the DOB design is the low-pass filter Q, and secondly, the main concern is the tradeoff between making $|Q(jw)|$ small and $|1 - Q(jw)|$ small.

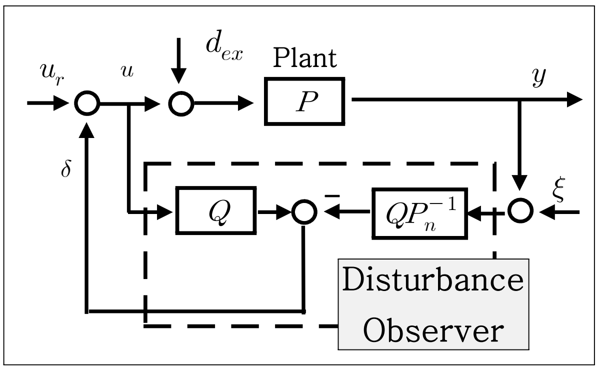


Fig.2 Disturbance Observer (DOB)

order	condition	performance
denominator m	⬆	robustness ⬆
numerator n	⬆	disturbance ⬆ rejection rate ⬆
relative r	⬆	robustness ⇩ sensor noise ⇩
time constant τ	⬆	sensor noise ⇩

Table.1 Factors of Q Filter

$$\sigma_{\max} \triangleq \left\| \begin{bmatrix} (1-Q(s)) & (1-Q(s))P_n(s) \\ -Q(s)P_n(s)^{-1} & -Q(s) \end{bmatrix} \right\| < \gamma \qquad (2)$$

DOB is made to disappear the effect of perturbation, but it doesn't mean to remove perfectly. Therefore, we need to be concerned about robustness. Since Eq(2) implies the degree of robustness of DOB system against the perturbation, we define it as "robustness measure of a DOB system" denoted by $\sigma_{\max}$. Actually, there are three important factors in designing a Q filter: the filter time constant, numerator order and denominator order (or relative degree) of Q filter. Studies in [4] and [5] papers show condition and performance of each factors at Table.1.

We apply to the filter using the Binomial filter design method. The method can consider to important facts. Now, we are to use the robustness measure Eq(2) as the design method of a Q filter for second-order systems. First, we assume the Q filter of the following form:

$$Q_{mn}(s) = \frac{\sum_{i=0}^{n} a_{mi}(\tau s)^i}{(\tau s + 1)^m} \qquad (3)$$

where τ is the filter time constant, $a_{mi} = \frac{m!}{(m-i)!i!}$ the binomial coefficient, m the denominator order and n the numerator order. Hence, $m \geq n+2$. Second, since ours system can be described by the second order transfer function, we assume that the nominal plant is given as follows:

$$P_n = \frac{k}{s^2 + 2(\zeta w_n s + w_n^2)} \qquad (4)$$

where, ζ is a damping ratio, w_n the undamped natural frequency and k a constant.

In short, this technique considers the numerator order, the denominator order and relative order of the nominal plant. The disturbance rejection performance

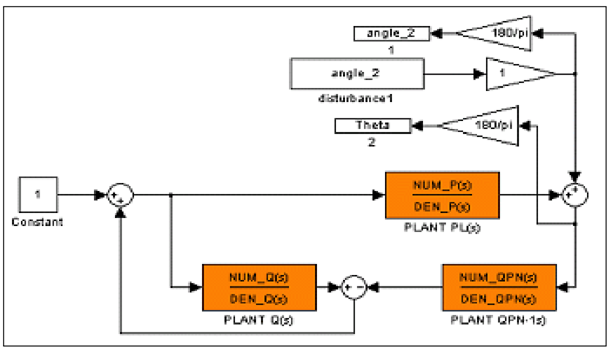


Fig.3 Structure of the simulink

of the filter depends on the numerator order and time constant. And robustness is decided by the denominator and relative order. Also, the relative order decides measurement noise reduction performance.

3 Design of DOB

Fig. 3 shows simulink at MATLAB based Fig.2 DOB. Where, Theta(2) is the Plant output and angle_2(disturance) disturbance signal, and the system uses unit step input.

3.1 Initial environment of Q Filter

Fig. 4 depicts maximum singular values of (2) according to frequencies. The robustness measure corresponds to the maximum among maximum singular values for each Q_{mn} filter. As we suggested in Table.1, the robustness becomes better

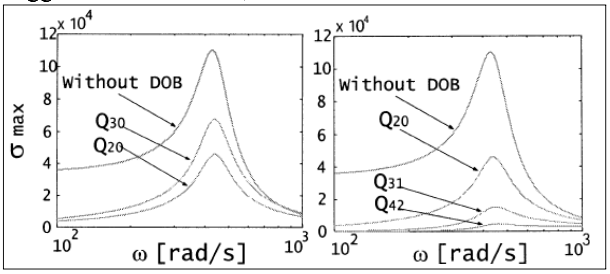
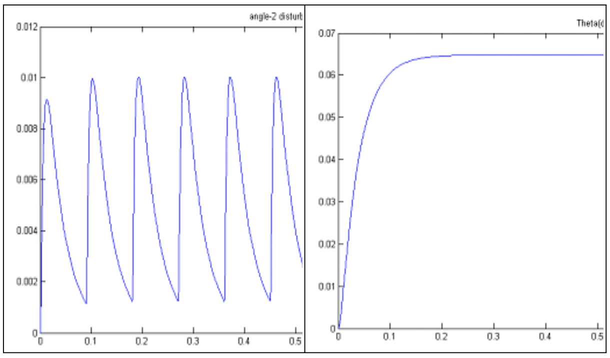


Fig. 4 Robustness comparison according to Q_{mn} firters



(a) Disturbance (b) Response without disturbance

Fig. 5 Disturbance & Response without disturbance (deg)

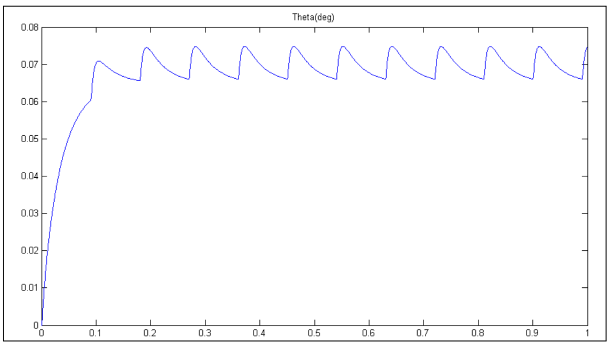


Fig. 6 Response with disturbance

as the relative degree decreases and as the denominator order increases with the same relative degree[4]. Where, the Q_{mn} filter selects Q_{42} (relative degree is two) And it proved through simulation. Fig.7 shows effect of disturbance in response without disturbance in Fig.5.

3.2 Design of Important Parameter

The system model is defined as

$$P(s) = \frac{6.19s^2 + 44.13s + 0.00006265}{s^4 + 226s^3 + 0.00001092s^2 + 0.000000219} \quad (5)$$

To decide optimum parameters of DOB, is referred Table.1 about factors effect. In order to prove performance of disturbance rejection, is used the simulink of MATLAB. It fix Q_{20} because of second-order system, find a optimum time constant τ. Fig. 7 shows results of simulation when τ change 0.0005 to 1. Where, a optimum time constant is 0.0005. And, Fig. 8 is results of simulation to decide denominate order. And optimum denominate order confirm forth-order. Finally, Fig. 9 shows results about numerator order change (τ is 0.0005, denominate order is forth-order). We can estimate optimum nominal order of second-order.

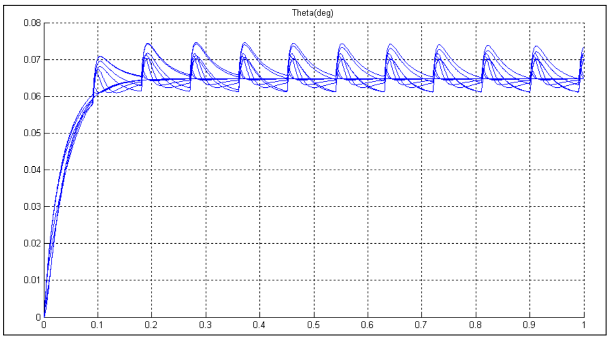
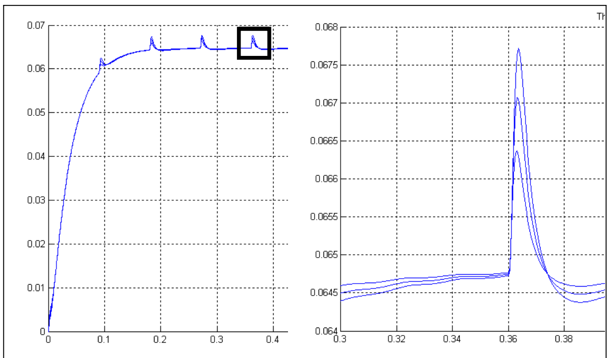


Fig.7 Response according to τ (Q_{20})
τ=1, 0.5, 0.1, 0.05, 0.01, 0.005, 0.001, 0.0005



(a) Full view (b) Detail view

Fig. 8 Response according to d (τ=0.0005, n=0)
Rejection performance : $Q_{20} < Q_{30} < Q_{40}$

Q filter can design to simulation. In short, a time constant is 0.0005, relative order second-order, denominator order forth-order, and numerator order second-order.

3.4 Stabilization

Also, Fig. 9 shows performance of disturbance rejection. Where, output angle is changed 0.01 ° to 0.0005 ° degrees after Q_{42} filter design. Namely, disturbance rejection rate is over 95%. In order to consider degree of stability, is used to five times of disturbance. The effectiveness of the disturbance observer in rejecting high shock disturbances is demonstrated in simulation. In the Fig. 10, the simulation shows disturbance rejection performance over 95%.

4 Conclusions

This paper presents improving performance of high shock disturbance rejection. We propose a disturbance observer (DOB) system for an instrument that is affected by regular shock. To consider to important facts, apply to the filter using the Binominal filter design method. Optimum value of the Q filter parameters is found through simulation using simulink of MATLAB. In order to consider degree of stability, is used to five times of disturbance. Then demonstrates disturbance rejection performance over 95%.

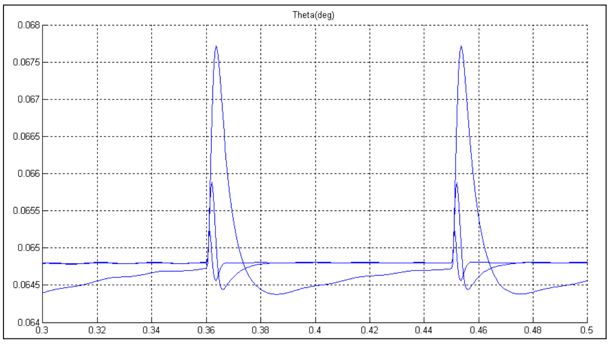


Fig. 9 Response according to numerator (τ=0.0005, d=4)
Rejection performance : $Q_{40} < Q_{41} < Q_{42}$

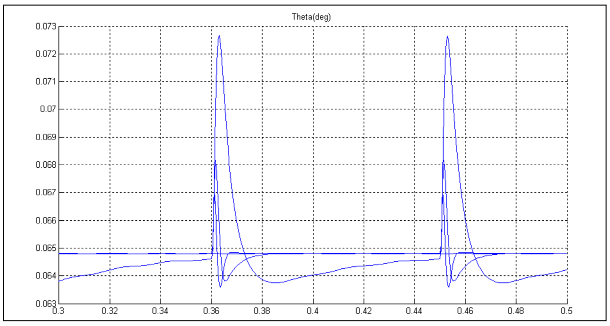


Fig. 10 Five times of disturbance
Rejection performance : $Q_{20} < Q_{31} < Q_{42}$

Acknowledgment

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