Parameters tuning approach for prescribed performance function based active disturbance rejection control

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Abstract

Active disturbance rejection control (ADRC) is a control approach which needs less information of the controlled plants/processes. However, there are many parameters in the nonlinear functions utilized in ADRC, so many parameters make the tuning of ADRC be a challenge. Prescribed performance function based ADRC is proposed and the tuning approach is studied in this paper. Some typical controlled plants are considered in the simulations. Numerical results are presented to support the proposed control approach and its tuning method.

Keywords: ADRC, prescribed performance function, parameter tuning

1. Introduction

Active disturbance rejection control (ADRC) is a control approach first proposed by Prof. Han in early 1990s.[1] ADRC was proposed by reconsidering the essence of control problem. Its basic idea is to make the control system be more robust to disturbance and uncertainties by estimating and compensating those factors actively in real time.

For the idea of ADRC, standard form of any system is the chain of integrators. The difference between the model and standard form will be viewed as disturbance or uncertainties. Extended state observer (ESO), the key part of ADRC, composed of the state observer and an extended state, is designed to estimate the disturbance and uncertainties in real time. And any control law can be designed in order to achieve the desired performance.

Nowadays, ADRC is relatively common in numerous applications, such as superconducting RF cavities,[2] piezoelectric beam,[3] nanopositioning.[4] The theoretical analysis is also given in Ref. 5, 6 and 7. Although there are many successful applications and valid theoretical analysis, the number of controller parameters one has to determine is a headache for engineers. In other words, engineers are difficult to set a group of applicable values for those tunable parameters. The value of parameters depends greatly on experience of engineers. Such problem limits ADRC's application more or less, even if ADRC is effective in control engineering.

As a matter of fact, for our part, the reason for the difficulties in tuning is that the parameters are of no physical explanations in ADRC.

With an attempt to get an easier and a more effective approach to fix the parameters of ADRC, Prof. Gao propose a bandwidth-parameterization based controller tuning approach.[8] By such proposal, engineers are able to get a clearer physical explanation for tunable parameters, and the tuning work becomes easier. However, such approach is based on the linear version of ADRC, i.e. LADRC. Tunable parameters can be got by an easier way, but the performance will be reduced as a result of taking linear extended state observer (LESO) or LADRC.

How to get an easier tuning approach and also retain the control performance by utilizing nonlinear function? This is a desired goal from both practical and theoretical view of point. In this paper, we have proposed prescribed performance function based active disturbance rejection control (PPF-ADRC), and given out the tuning approach. The parameters one has to determine have clear physical explanations and the simulation results confirm the proposed approach.

The remainder of the paper is organized as follows. Section 2 gives out the basic structure of LADRC. PPF-ADRC is designed in Section 3. Simulation results and conclusions are offered in Section 4 and 5 respectively.

2. Linear Active Disturbance Rejection Control

Generally, LADRC is designed by linearize the estimation error, the control block diagram for 3rd-order LADRC can be shown in Fig. 1.

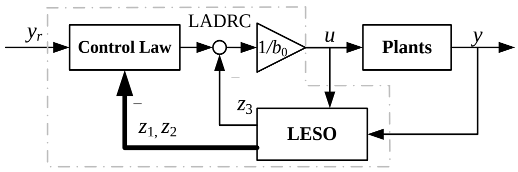

Fig. 1 Control block diagram for 3rd-order LADRC

The dynamics of LADRC can be described as [8]

$$\begin{cases} \dot{z}_1 = z_2 + \beta_1 e(t) \\ \dot{z}_2 = z_3 + \beta_2 e(t) + b_0 u \\ \dot{z}_3 = \beta_3 e(t) \end{cases} \tag{1}$$

$$u = [k_p(y_r - z_1) - k_d z_2 - z_3]/b_0 \tag{2}$$

where y_r is the desired system output, u is the control input, k_p, k_d are control gains, b_0 is the coefficient of control input, $e(t)$ is the estimation error, and $e(t) = y - z_1$. z_1, z_2 and z_3 are outputs of LESO respectively. z_1 estimates system output y , z_2 estimates $\dot{y}$, z_3 is the estimation of total disturbance and uncertainties. β_1, β_2 and β_3 are gains of LESO.

3. Prescribed Performance Function based Active Disturbance Rejection Control Design

In order to improve the efficiency of LESO, in this paper, we still take advantage of nonlinear function in ESO, but the parameters for the nonlinear function have clear physical explanations.

Firstly, a prescribed performance function, a positive decreasing smooth function, is introduced.

$\rho(t): R^+ \mapsto R^+$, and $\lim_{t\to\infty} \rho(t) = \rho_\infty > 0$, it can be defined as

$$\rho(t) = (\rho_0 - \rho_\infty)\exp(-lt) + \rho_\infty \tag{3}$$

where $\rho_0 > \rho_\infty, l > 0$. ρ_0 is the maximum value of allowable estimation error, ρ_∞ is the maximum value of allowable steady estimation error, l determines the decreasing rate of $\rho(t)$.

Then, we may define $\gamma(t)$ satisfying,[9]

$$-\underline{\delta}\rho(t) < \gamma(t) < \bar{\delta}\rho(t) \tag{4}$$

where $0 < \underline{\delta}, \bar{\delta} \le 1$ are prescribed scalars. By (4), we can see that function $\gamma(t)$ is defined in a prescribed range.

For the sake of satisfying the constrained condition (4), a smooth and strictly increasing function $S(x)$ can be defined,

$$-\underline{\delta} < S(x) < \bar{\delta} \tag{5}$$

$$\lim_{x\to\infty} S(x) = \bar{\delta}, \lim_{x\to-\infty} S(x) = -\underline{\delta} \tag{6}$$

We can introduce a transformation

$$\gamma(t) = \rho(t)S(x) \tag{7}$$

then property (4) can be described as,

$$-\underline{\delta}\rho(t) < \gamma(t) = \rho(t)S(x) < \bar{\delta}\rho(t) \tag{8}$$

If we let $\gamma(t)$ be estimation error, from inequality (8), we can see clearly that estimation error will be always within the prescribed range.

Actually, the estimation error reflects the system's ability of disturbance estimation and compensation in a great extent. If estimation error is within a prescribed range from the beginning, it means that ESO has stronger power in estimation and compensation disturbance and uncertainties. Therefore, we introduce a transformation. Let $x = e(t)$, then transformation (7) can be rewritten as

$$e_o(t) = \rho(t) S(e(t)) \qquad (9)$$

where $e_o(t)$ is the transformed estimation error, which satisfies property (8).

Then we use the transformed estimation error $e_o(t)$ in error transformation based ESO (ETESO),

$$\begin{cases} \dot{z}_1 = z_2 + \beta_1 e(t) \\ \dot{z}_2 = z_3 + \beta_2 e_o(t) + b_0 u \\ \dot{z}_3 = \beta_3 e_o(t) \end{cases} \qquad (10)$$

In the design, we choose function $S(x)$ as

$$S(x) = \frac{\bar{\delta}\exp(x) - \underline{\delta}\exp(-x)}{\exp(x) + \exp(-x)}$$

Accordingly, PPF-ADRC can be obtained((2) and (10)).

4. Simulation Results

With an attempt to verify the performance of PPF-ADRC, we have performed two simulations. Refer to Ref. 10, two plants are considered.

Table 1. Plants and its models

Plant	Model
P_1	$G_1(s) = \frac{e^{-5s}}{(s+1)^3}$
P_2	$G_2(s) = \frac{1-2s}{(s+1)^3}$

For the plants shown in Table 1, we design both PPF-ADRC and LADRC. Controller parameters chosen approach refers to Ref. 8.

For the controller part, we take the bandwidth-parameterization approach. For the ETESO part, $\beta_1, \beta_2, \beta_3$ are also taken bandwidth-parameterization approach into consideration. Parameters for error transformation part refer to their physical explanations. Parameter values chosen in simulations are shown in Table 2.

Table 2 PPF-ADRC parameters

	b_0	ω_o	ω_c	ρ_0	ρ_∞	l	$\underline{\delta}$	$\bar{\delta}$
P_1	3	1.6	0.3	0.291	0	0.3	1	0.8
P_2	15	4	1	.18	0	1	1	0.1

In simulations, controller parameters and the gain of ESO in LADRC and PPF-ADRC are chosen the same value. Simulation results are shown in Fig. 2 and 3, respectively. Both subfigures (e) and (f) in Fig. 2 and 3 depict the tracking error $e_c(t)$, i.e. the error curves between y and y_r.

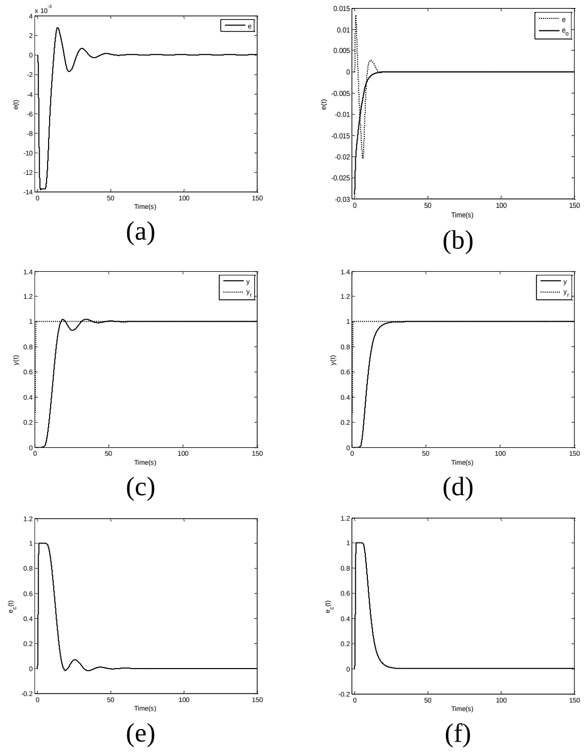

Fig. 2 Comparisons of system response(for P_1)

Table 3. Comparisons of IAE Values(For P_1)

Controller	IAE Value
LADRC	12.4144
PPF-ADRC	10.8236

From Fig. 2, we can see clearly that the response of LADRC ((a),(c), and (e)) is inferior to the response of PPF-ADRC((b),(d),and (f)), when control parameters and the gains of ESO are chosen the same. Comparisons of integral of absolute error (IAE) values are given in Table 3.

Fig. 3 demonstrates that PPF-ADRC is also superior to LADRC when control parameters and the gains of ESO are chosen the same. Comparisons of IAE values are shown in Table 4.

In this section, typical systems including delay and unstable unit are considered. Both system response and IAE values confirm that PPF-ADRC has better performance than LADRC. Actually, advanced design idea guarantees better performance of PPF-ADRC.

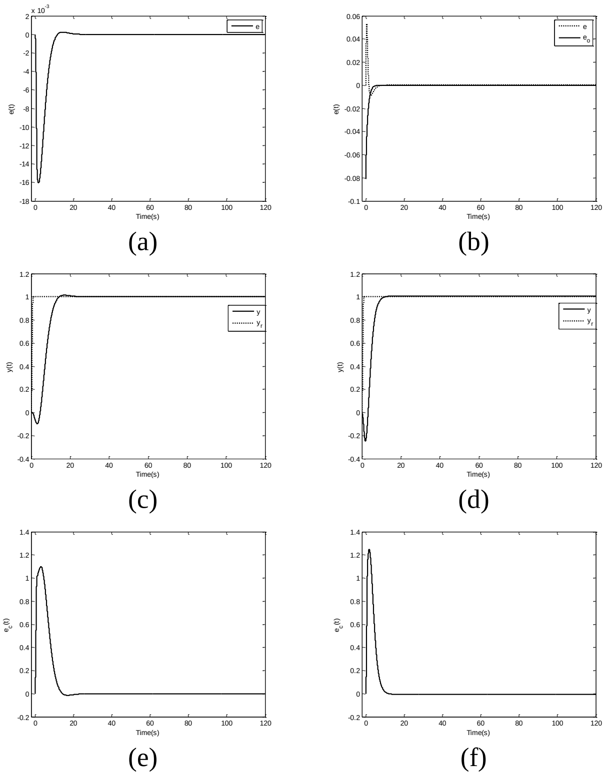

Fig. 3 Comparisons of system response(for P_2)

Table 4. Comparisons of IAE Values(For P_2)

Controller	IAE Value
LADRC	7.8713
PPF-ADRC	5.9112

5. Conclusion

In this paper, based on the prescribed performance function and the idea of error transformation, we have proposed PPF-ADRC. Parameters of PPF-ADRC are chosen according to the bandwidth-parameterization approach and the physical explanation of prescribed performance function. Two typical examples are taken to confirm PPF-ADRC and its parameters tuning method. Numerical results confirm that, by introducing nonlinear prescribed performance function and error transformation, PPF-ADRC not only has a relatively easier tuning approach, but also can improve the control performance effectively.

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