Modeling and Simulation of Linear Active Disturbance Rejection Controller in Simulink

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Abstract. The principle and structure of linear active disturbance rejection controller (LADRC) are analyzed, and the algorithm of the controller is clarified and the parameter setting process is simplified. Completing the creation and packaging of functional modules of linear active disturbance rejection controller by Simulink modeling idea and creating a module library of linear active disturbance rejection controller. The validity of linear active disturbance rejection controller and the effectiveness of the modeling method are described by linear active disturbance rejection control simulation of a second—order nonlinear time—varying object.

Introduction

In view of the shortcomings of classical PID control technology, Han Jingqing researcher put forward the active disturbance rejection controller (ADRC) [1]. This controller not only inherits the advantages of PID control, but also does not rely on the exact mathematical model of the controlled object. Under the unknown uncertain disturbance, the controller can still estimate and compensate the uncertain factors of the system, so it has strong robustness. However, the non-linear mechanism is used in three parts of the expansion state observer (ESO), the tracking differentiator (TD) and the nonlinear feedback control in ADRC, which makes the theoretical analysis difficult. The steady-state high gain caused by nonlinear feedback is easy to cause jitter in small signal, and parameter tuning of ADRC is very complicated, so it is difficult to promote and application for ADRC [2]. Gao Zhiqiang et al. transform the non-linear mechanism of various components in ADRC into linear form [3,4], and so obtain linear active disturbance rejection controller (LADRC). LADRC uses the concept of bandwidth to simplify parameter tuning process on the basis of preserving the control effect of non-linear ADRC, and it has achieved good control effect in many industries [5-7].

Simulink is a kind of visual simulation tool in MATLAB, which is widely used in the modeling and simulation of control system. LADRC model is generally quite complicated, and it will take a lot of time to model and simulate in MATLAB/Simulink. Therefore, the components of LADRC can be encapsulated into the corresponding function module [8], and then add them to built-in custom LADRC module library, so that they can be called directly in the future simulation, and then saving modeling time.

The Composition and Principle of LADRC

LADRC Structure

LADRC is linear form of ADRC, which is made up of four parts: transition process, linear expansion state observer (LESO), disturbance compensation and PD control, the structure is shown in Fig.1.
The transition process uses a relatively gentle, smooth way to transit the mutated portion of the reference signal, so as to reduce the impact of signal mutation on the controlled system, and it finally outputs the tracking signal and differential signal of the reference signal; LESO estimates dynamic characteristics of the system and real-time interaction of the external disturbance according to system control, output and special feedback mechanism; disturbance compensation link compensates the estimated disturbance action into the controller, making original system into linear series integration system, and the integral system is controlled by PD control. Through the above four links, LADRC can finally realize the real-time estimation and on-line compensation of disturbances.

Mathematical Algorithm of LADRC

Linear functions are used in each component of LADRC, so the LADRC algorithm is relatively simple. The transition process can be implemented by a linear tracking differentiator (LTD) or a function generator. A typical second-order LADRC algorithm is as follows:

(a) LTD

LTD is used to smooth reference signal, and outputs tracking signal and differential signal of the reference signal, the algorithm is as follows:

\[
\begin{align*}
\dot{v}_1 &= v_2 \\
\dot{v}_2 &= -k_1(v_1 - v_0) - k_2 v_2
\end{align*}
\]

where \(v_0\), \(v_1\), \(v_2\) are reference signal, tracking signal and differential signal of the system, \(k_1\), \(k_2\) are adjustable parameters of LTD, when \(k_1 = r^2\), \(k_2 = 2r\), \(r > 0\), the transition process is not overshoot, and transition time is about \(T_o = 7 / r\), \(r\) is speed factor.

(b) LESO

LESO can estimate state variables including disturbances, as follows:

\[
\begin{align*}
\dot{z}_1 &= z_2 - \beta_1(z_1 - y) \\
\dot{z}_2 &= z_3 - \beta_2(z_1 - y) + b_0 u \\
\dot{z}_3 &= -\beta_3(z_1 - y)
\end{align*}
\]

where \(z_1\), \(z_2\), \(z_3\) are estimated values of \(y\), \(\dot{y}\) and disturbance \(f(\cdot)\), \(b_0\) is amplification factor, \(\beta_1\), \(\beta_2\), \(\beta_3\) are LESO gains, and the following relation is satisfied: \(\beta_1 = 3\omega_0\), \(\beta_2 = 3\omega_0^2\), \(\beta_3 = \omega_0^3\), \(\omega_0\) is observer bandwidth \([3]\), it can make \(z_1 \rightarrow y\), \(z_2 \rightarrow \dot{y}\), \(z_3 \rightarrow f(\cdot)\) by adjusting gains.

(c) Disturbance compensation

After the disturbance is estimated, the following compensation control can be designed for dynamic compensation, and then the original system is converted into a series integration system. the algorithm is as follows:

Figure 1. Structure diagram of LADRC.
\[ U = \frac{U_0 - z_3}{b_0} \]  

where \( U_0 \) is the PD feedback control amount.

(d) PD controller

In order to avoid the differential of the given signal and make the closed-loop transfer function a pure second-order transfer function that does not contain zero point, the PD control algorithm is rewritten as \(^3\).

\[ U_0 = k_p(y_d - z_1) - k_Dz_2 \]  

where \( y_d \) is the reference trajectory, \( k_p, k_D \) are controller gains and meet the following relationship:

\[ k_p = \omega_c^2, k_D = 2\omega_c, \omega_c \] is adjustable parameter of PD controller.

LADRC Modeling

The Creation and Encapsulation of Function Modules in LADRC

Simulink provides a function that create and encapsulate function modules, just defines some functional modules in accordance with its requirements, these modules can be directly called in Simulink simulation.

Taking the second-order LESO as an example to introduce how to create and encapsulate function modules. Firstly, LESO simulation model is established in model window according to the LESO algorithm, as shown in Fig.2; and then select this model and click “Create Subsystem” in “Edit” menu, so the functional module is created; finally, we need to encapsulate it, the packaging process is as follows:

1. Select the created functional module, open “Mask Subsystem” in “Edit” menu into “mask” edit window, and then set four tabs respectively in the edit window.
2. Set text name of the function module according to “disp” command in “Icon Drawing Commands” of the “Icon&Ports” tag, such as input “disp ('LESO')”, and then “LESO” is displayed on the function module.
3. In “Parameters” tab, set the input prompt (prompt) and the parameter name (variable) to be adjusted, such as \( \omega_c \).
4. Design the text specification and “Help” for the function module in “Documentation” tab. Finally click “OK” to complete the encapsulation of the function module, as shown in Fig.3.

Parameter setting window as shown in Fig.4 will appear when double-clicking on the encapsulated function module. Adjust the values of parameter \( \beta_1, \beta_2, \beta_3 \) just by changing \( \omega_c \) in the window, so it is very convenient. The creation and encapsulation process of function modules of the transition process and PD control is the same as LESO, this is not repeated here.
Establishment of LADRC Module Library

In order to focus on function modules that have been established so that we can call them later, we can create a custom LADRC module library in Simulink. Specific steps are as follows:

1. Build module library file
   Open “Library” window in Simulink, add encapsulated function modules to the window, and then save it.

2. Create sub-library of the module library
   Open the above-mentioned established library files to create and encapsulate functional modules for each module included in the sub library and delete input and output ports of the encapsulated function module.

3. Display module library
   A “Browser” structure is defined in “slblocks.m” file to display the library name, here for “LADRC”, and then save it to the same directory as the created library file and put this directory into the MATLAB path. When opening Simulink again, we can see the LADRC module library, as shown in Fig.5.

Simulation Example

Taking the second-order nonlinear time-varying object as an example to illustrate the practicability and validity of the above modeling method and the correctness of LADRC algorithm.

There is a second-order system as follows:
\[
\begin{align*}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= f(x_1, x_2, t, w(t)) + bu \\
y &= x_1
\end{align*}
\]
where \( b = 1 \), the estimated value \( b_0 \) of \( b \) is taken as 1, and the total disturbance is taken as:

\[
f(x_1, x_2, t, w(t)) = x_1^2 \cos(0.6t) + 0.2x_2 \cos(0.7t) + \text{sign}(\sin(1.5t)), \quad w(t) = \text{sign}(\sin(1.5t)).
\]

Build simulation diagram and perform mathematical simulation according to the above modeling method and Fig.1 in MATLAB /Simulink environment, as shown in Fig.6.

![Simulation model of LADRC system.](image)

Figure 6. Simulation model of LADRC system.

When controller parameters are taken as \( r = 7, \omega_c = \omega_0 = 150 \), the simulation results are shown in Fig.7.

![System output tracking.](image)

(a) System output tracking.

![Disturbance estimation.](image)

(b) Disturbance estimation.

Figure 7. LADRC simulation response of the second-order system.

It can be seen from Fig.7(a) that the system output signal can be fast following input without overshoot, and the steady-state error is close to zero. Fig.7(b) shows the observation effect of system disturbances, as can be seen from Fig.7(b), LESO can identify the total disturbance at a faster rate.

**Summary**

This paper describes the structure, principle and algorithm of LADRC, and discusses the creation and encapsulation of functional modules of LADRC. It not only makes the LADRC simulation model simple, but also facilitates parameter tuning through the encapsulation of the module. Finally, LADRC module library is defined, and then function modules in LADRC are concentrated...
in the library, which can be called directly in the future simulation, thus saving time and greatly improving the modeling and simulation efficiency.

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