PROJECT

ACTIVE DISTURBANCE REJECTION CONTROL

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INTRODUCTION

- The Active Disturbance Rejection Control block lets you design active disturbance rejection control (ADRC) for a plant with unknown dynamics and internal and external disturbances.
- ADRC is a model-free control technique that requires only an approximation of the plant dynamics to design controllers that provide robust disturbance rejection.
- The block uses a first-order or second-order model approximation of the known system dynamics along with the unknown dynamics and disturbances modeled as an extended state of the plant.
- Typically, you determine this order from the open-loop step response of your plant in the operating range.

First-order approximation —

$$\dot{y}(t)=b0u(t)+f(t)$$

Second-order approximation —

$$\ddot{y}(t)=b0u(t)+f(t)$$

Here:

***y*(*t*) is the plant output.**
***u*(*t*) is the input signal.**

b_0 is the critical gain, which is the estimated gain that describes the plant response to an input $u(t)$.
$f(t)$ is the total disturbance, which includes unknown dynamics and other disturbances.

The block uses an extended state observer (ESO) to estimate $f(t)$ and implements disturbance rejection control by reducing the effect of estimated disturbances on the known part of model approximation. To tune ADRC, set appropriate time domain, model type and critical gain, controller and observer bandwidths, and initial conditions.

- **Core Idea :**

"Observe the disturbance → Estimate it → Cancel it in real-time."

KEY COMPONENTS OF ADRC :

•**Tracking Differentiator (TD):**
•Smooths and differentiates the reference signal
•Helps avoid overshoot and oscillation

•**Extended State Observer (ESO):**
•Observes both system states and total disturbance
•Replaces the need for an accurate model

•**Nonlinear State Error Feedback (NLSEF):**
•Produces the control signal using estimated states and disturbances
•Allows fast, nonlinear correction

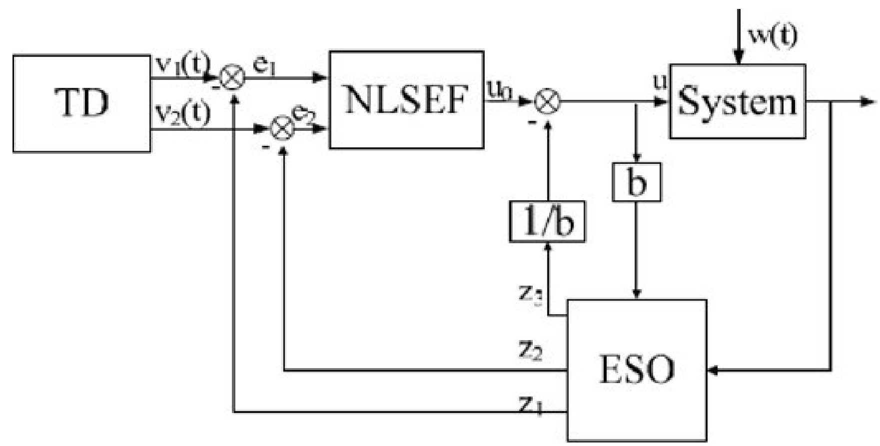


Fig:2 ADRC Block Diagram

WORKING PRINCIPLE OF ADRC :

❑ **Input Signal Processing (Tracking Differentiator - TD):**

•Smooths the reference input.

•Generates derivatives for better tracking without noise amplification

❑ **State and Disturbance Estimation (Extended State Observer - ESO):**

•Observes both system states and disturbances.

•Augments the system by treating the disturbance as an extended state.

❑ **Disturbance Rejection (Controller / NLSEF):**

•Uses the estimated states and disturbance to compute a control signal.

•This control action cancels out the disturbance’s effect on the system.

❑ **Control Output Applied to Plant:**

•The plant responds with a minimized error due to active compensation.

MATHEMATICAL FORMULATION OF ADRC : LINEAR.

Active Disturbance Rejection Control (ADRC) is fundamentally different from classical control methods in that it does not attempt to fully model the system dynamics. Instead, ADRC focuses on **observing and canceling the total disturbance** — which includes both internal model uncertainties and external disturbances — in real-time. The mathematical foundation of ADRC lies in rethinking how we represent and handle disturbances within the control system.

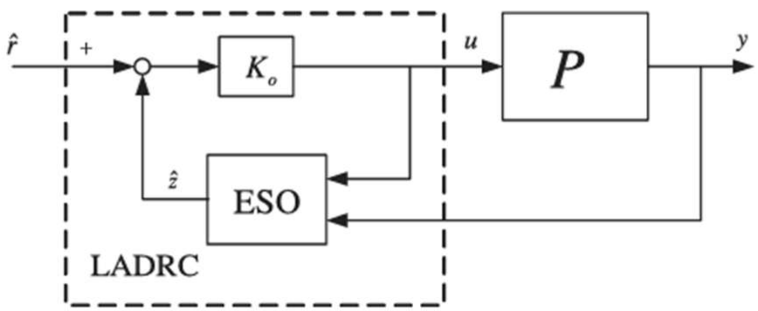


Fig. 1. Structure of LADRC.

- **Control Law (LADRC)**

Objective: Drive output y(t) to track reference r(t)

Define errors:

$$y^{(p)}(t) = b_0 u(t) + f(y, \dot{y}, \ldots, y^{(p-1)}, u, \dot{u}, \ldots, u^{(p)}, t)$$

Where f is a combination of the unknown dynamics and the external disturbance of the plant ,and denoted as the generalized disturbance. To estimate f ,assume that f is differentiable and let h= $\dot{}$ f, then an extended state – space realization of (1) is

$$\dot{z} = A_e z + B_e u + E_e h$$

$$\hat{y} = C_e z$$

With the state

$$z = y,$$

$$z_2 = \dot{y}, \ldots, z_p = y^{(p-1)}, z_{(p+1)} = f$$

And state- space matrices

$$A_e = \begin{bmatrix} 0 & 1 & 0 & \ldots & 0 \\ 0 & 0 & 1 & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & 0 & \ldots & 1 \\ 0 & 0 & 0 & \ldots & 0 \end{bmatrix}_{(p+1)\times(p+1)}$$

$$B_e = \begin{bmatrix} 0 & 0 & \ldots & b_0 & 0 \end{bmatrix}^T_{(p+1)\times 1}$$

$$E_e = \begin{bmatrix} 0 & 0 & \ldots & 0 & 1 \end{bmatrix}^T_{(p+1)\times 1}$$

$$C_e = \begin{bmatrix} 1 & 0 & 0 & \ldots & 0 \end{bmatrix}_{1\times(p+1)}$$

In an ADRC framework, an ESO is used to estimate the unknown generalized disturbance (f). A linear ESO has the following form:

$$\dot{\hat{z}} = A_e \hat{z} + B_e u + L_0 (y - \hat{y})$$

$$\hat{y} = C_e \hat{z}$$

Where Lo Is the observer gain vector

$$L_0 = \begin{bmatrix} \beta_1 & \beta_2 & \ldots & \beta_p & \beta_{p+1} \end{bmatrix}^T$$

When Ae−Lo Ce is asymptotically stable, z1(t),...,zp(t) will approximately (t) and its derivatives (up to order p−1), and zp+1(t) will approximate the generalized disturbance f. The estimated generalized disturbance can be used in control to reject it as in the following state-feedback law:

$$u(t) = \frac{k_1(r(t) - \hat{z}_1(t)) + \ldots + k_p(r^{(p-1)}(t) - \hat{z}_p(t))}{b_0} - \frac{\hat{z}_p + 1(t)}{b_0} =: K_0(\hat{r}(t) - \hat{z}(t))$$

Where r(t) is the reference signal,ˆ r(t)is an extended reference signal composed of the reference signal r(t),and its derivatives

$$\hat{r}(t) = \begin{bmatrix} r(t) & \dot{r}(t) & \ldots & r^{(p-1)}(t) & 0 \end{bmatrix}^T$$

Ko is the controller gain vector

$$K_0 = \lfloor k_1 \quad k_2 \quad \ldots \quad k_p \quad 1 \rfloor / b_0$$

In summary ,an LADRC has the following state-space form

$$\begin{aligned} \dot{\hat{z}} &= A_e\hat{z} + B_e u + L_o(y - C_e\hat{z}) \\ u &= K_o(\hat{r} - \hat{z}) \end{aligned}$$

COMPARISON WITH (PID) PROPORTIONAL–INTEGRAL–DERIVATIVE CONTROLLER :

Feature	PID Controller	ADRC (Active Disturbance Rejection Control)
Nonlinear System Handling	Limited	Suitable for nonlinear and time-varying systems
Control Accuracy	Acceptable in ideal conditions	High, even in uncertain environments
Model Requirement	No model required	Minimal model required (system order + gain estimate)
Robustness	Low	High
Implementation Complexity	Simple	More complex (observer + nonlinear control law)

❖ APPLICATIONS OF ADRC :

✓ **Aerospace / UAVs**

- Attitude and altitude control
- Robust flight control under wind disturbances

✓ **Robotics**

- Precise motion and trajectory tracking
- Joint control in robotic manipulators

✓ **Industrial Automation**

- Servo motor and actuator control
- CNC machines and manufacturing systems
- Process control in chemical/plants

✓ **Automotive Systems**

•Active suspension systems

•Electric power steering

•Vehicle stability and traction control

✓ **Electrical & Power Systems**

•DC/AC motor drives

•Power converters and inverters

•Grid-connected renewable systems

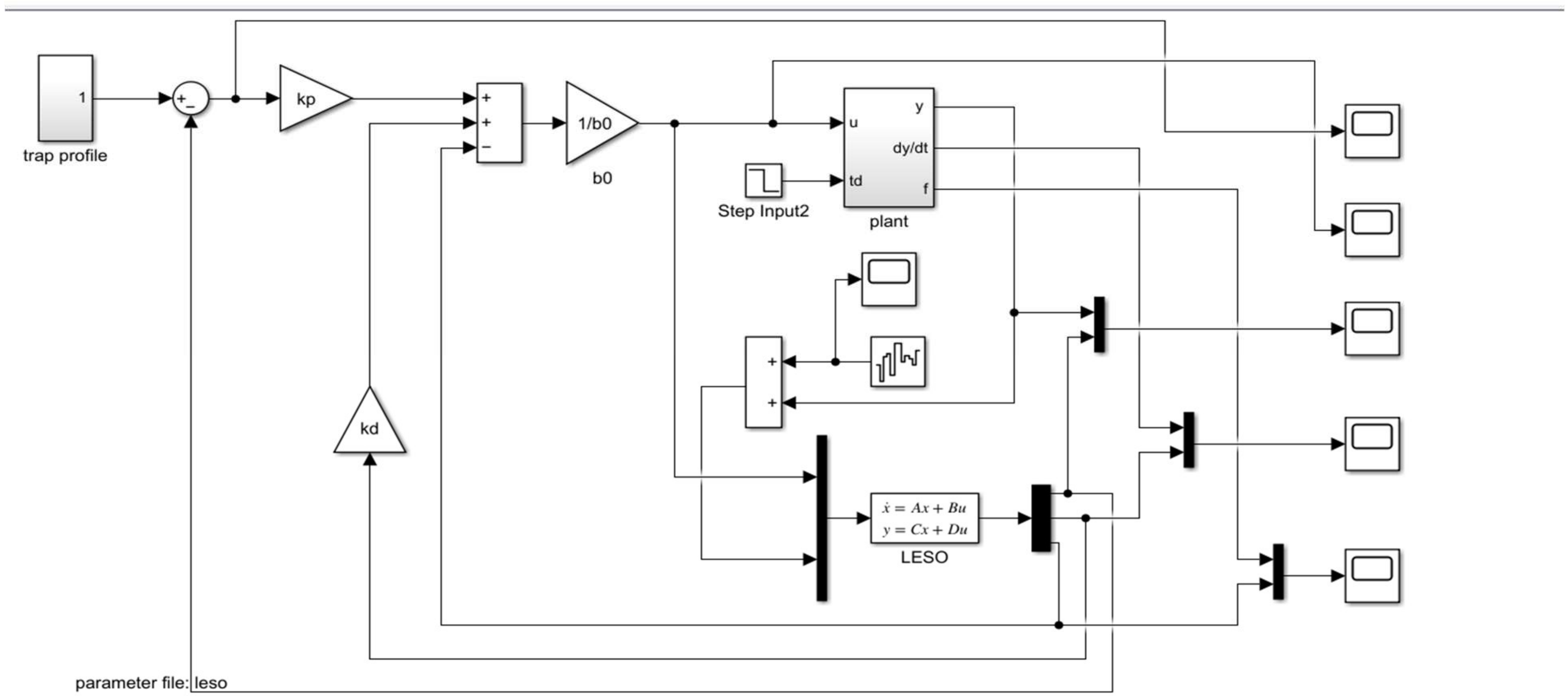
✓ **Biomedical Devices**

•Control of artificial heart pumps

•Precision in medical robotics and surgical tools

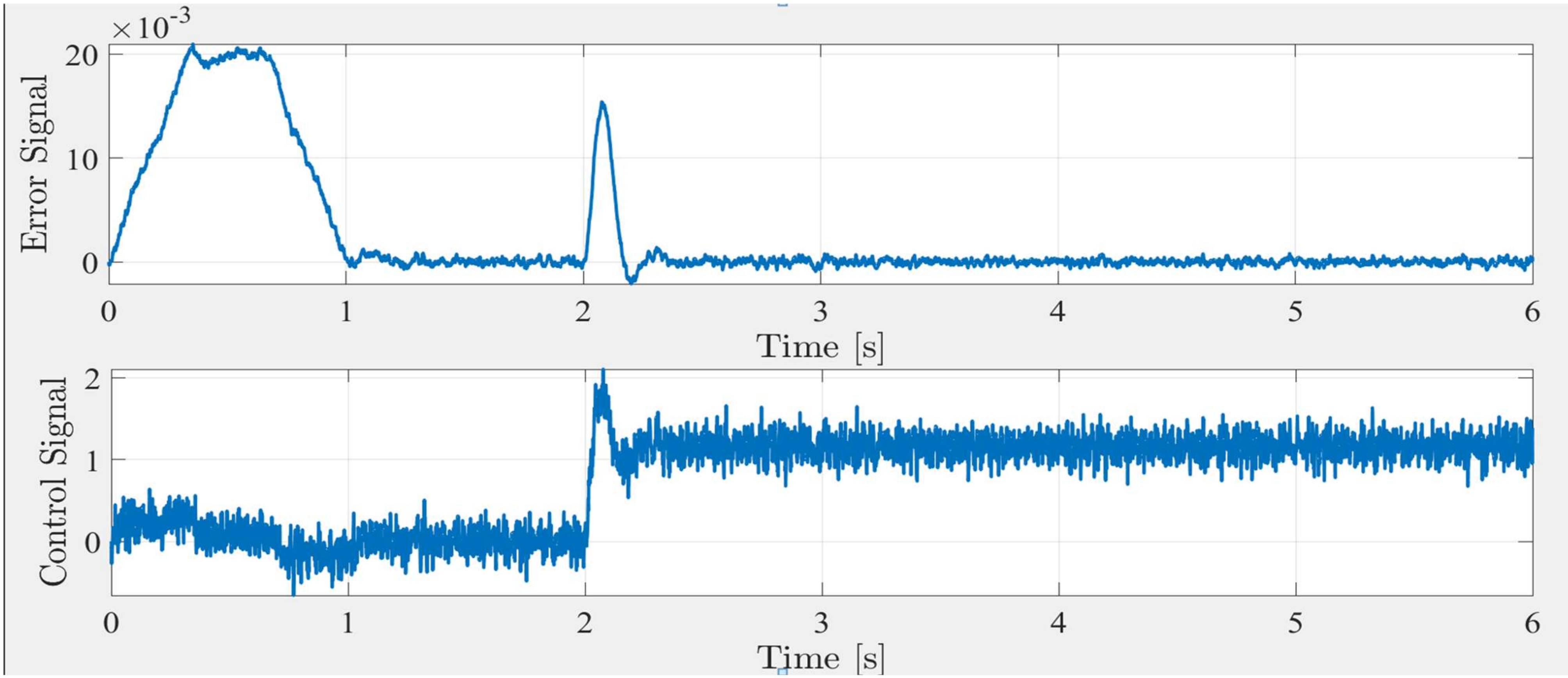
❖ CODE FOR ADRC

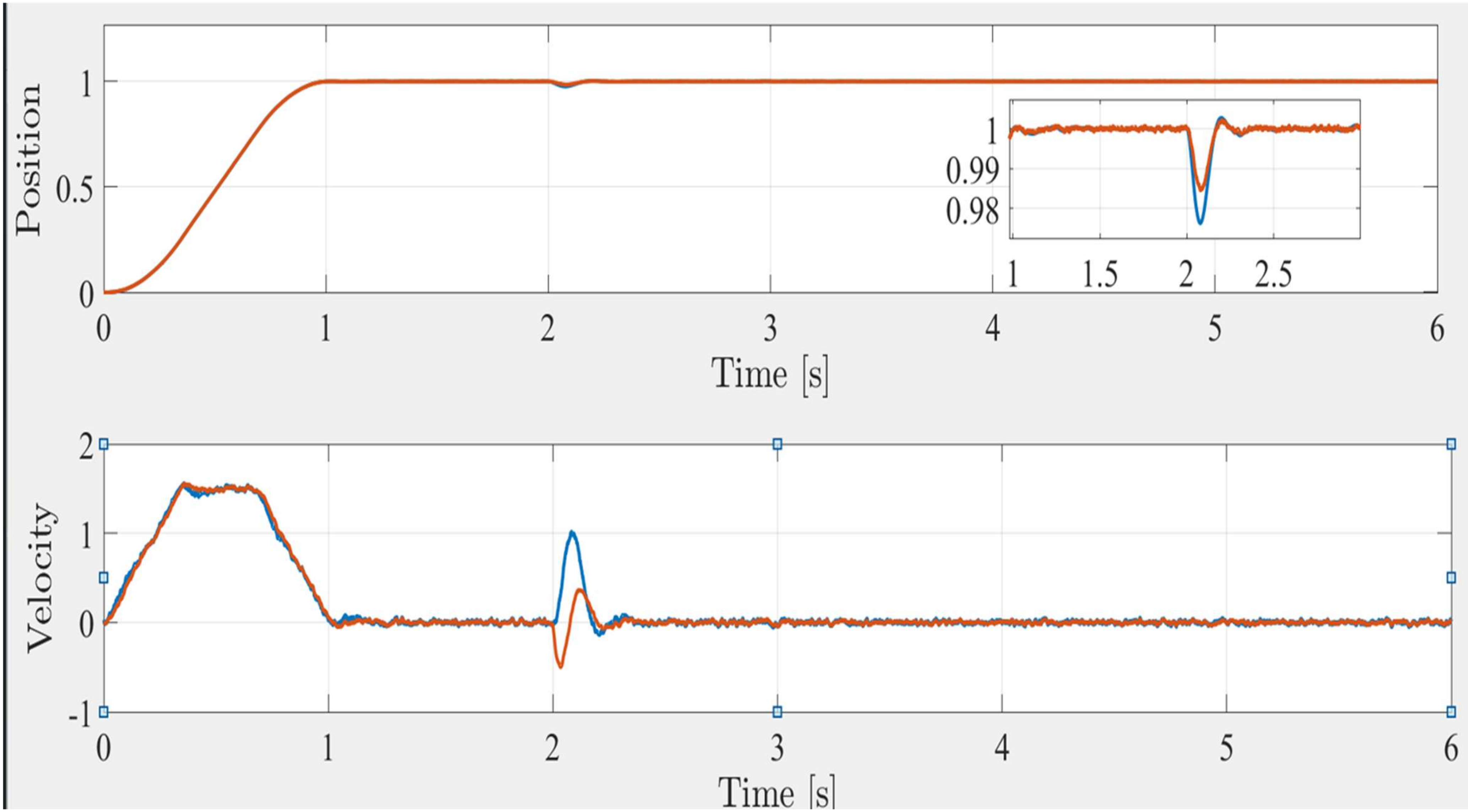
```
clc
clear all
h=1e-3; %simulation step
size
b0=40;
wo=40; %acc paper: 40
wc=150; %acc paper: 150
kp=wc^2;kd=-2.*wc;
sim('Motion_acc03');
```



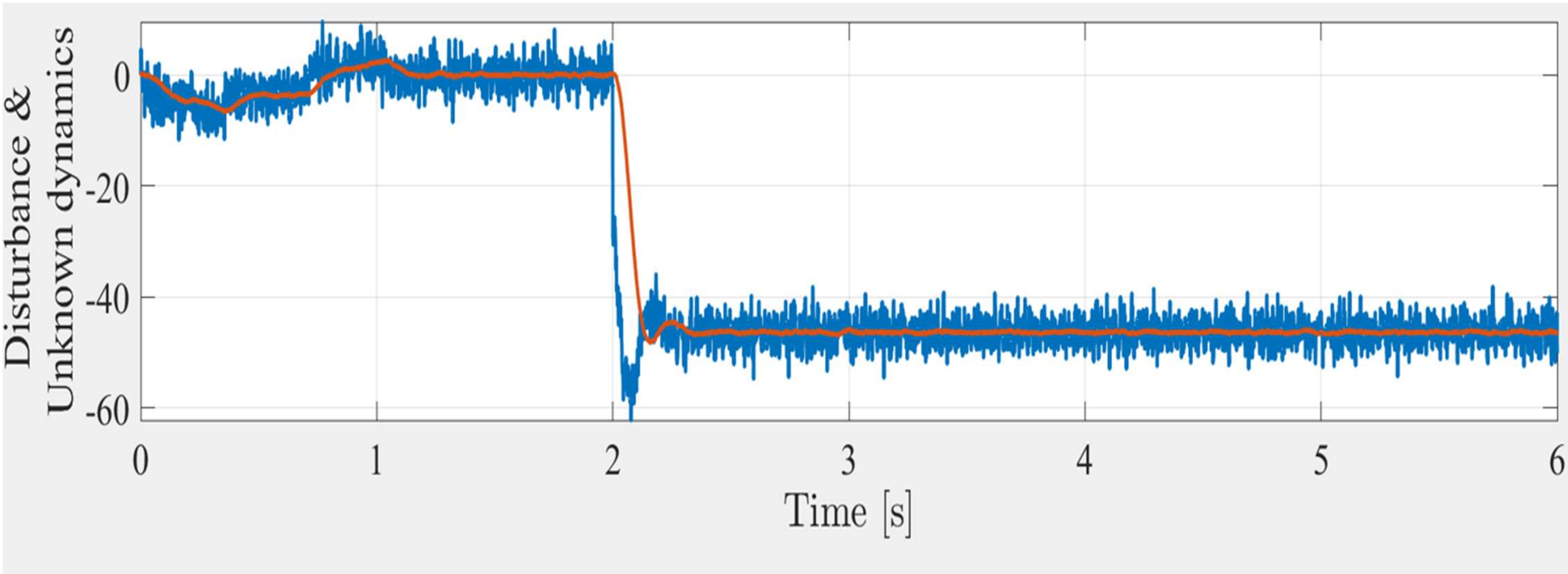
Application of ADRC with Adaptive Extended State Observer in Plant Dynamics

Simulation Results





Position
Time [s]
Velocity
Time [s]


Disturbance &
Unknown dynamics
0
-20
-40
-60
0
1
2
3
4
5
6
Time [s]

CHALLENGES OF ADRC:

1. Parameter Tuning:

- **Complexity:**
- ADRC controllers have numerous parameters that need to be tuned, making it challenging to find the optimal settings for various applications.
- **Manual Tuning:**
- Manual tuning of parameters can be time-consuming and may not always lead to the best performance.
- **Dynamic Systems:**
- ADRC can be more challenging to tune for systems with large lags or delays, such as those in power generation.

2. Performance Loss:

- **Simplified Model:**
- ADRC uses a simplified model, which can lead to performance losses compared to controllers that use a more accurate model of the systems

•**Disturbance Handling:**

•While ADRC excels at handling disturbances, the simplified model might not fully account for all disturbances, leading to less optimal performance.

3. Observer Performance:

•**Observer Dependence:**

•The effectiveness of ADRC relies heavily on the accuracy of the extended state observer, which estimates both the state and the total disturbance.

•**Plant Model Reliability:**

•The quality of the observer's performance depends on the reliability of the plant model used in the observer design.

•**Complexity of Plants:**

•Observer-based control approaches, like ADRC, can be more challenging to implement and analyze for complex systems

•**Nonlinearities:**

•ADRC needs to handle nonlinearities in the system, which can add to the complexity of the design and implementation.

❖ CONCLUSION

•ADRC is a **robust and modern control strategy** designed to handle disturbances and model uncertainties in real time.

•It provides **superior performance** compared to traditional PID controllers, especially in nonlinear or unpredictable environments.

•By estimating and rejecting the **total disturbance**, ADRC reduces dependency on precise mathematical models.

•The **Extended State Observer (ESO)** is the key component that enables real-time state and disturbance estimation.

•ADRC is widely applicable across domains like **aerospace, robotics, automotive, industrial automation, and power systems**.

•Despite its slightly higher complexity, ADRC offers **high adaptability, accuracy, and robustness**.

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