Robust Motion Control of Industrial Robot Considering Two-inertia System Based on CDM Method and Resonance Ratio Control

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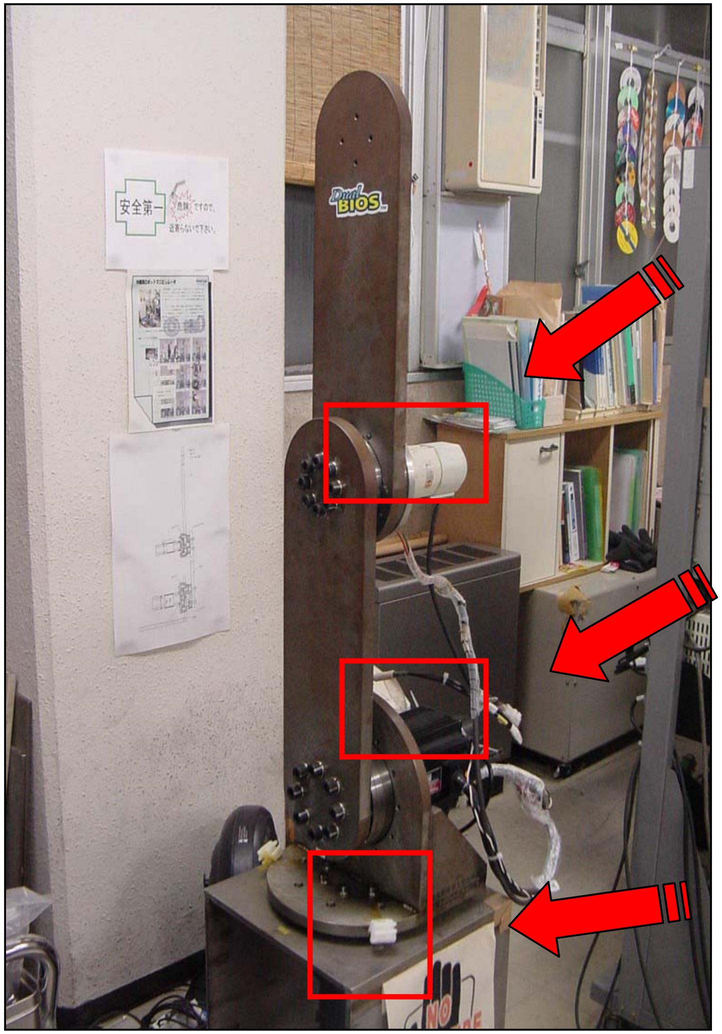
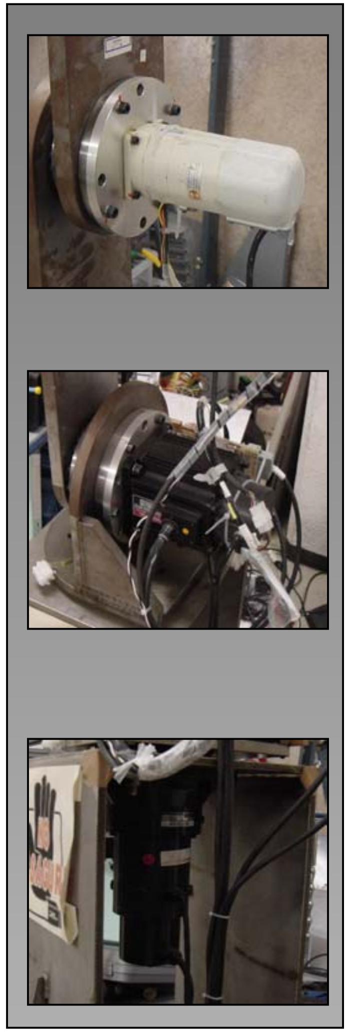
S&T in Thailand : Towards the Molecular Economy

Background

What’s need for industrial robot manipulators





High-accuracy

High-repeatability

High-precision

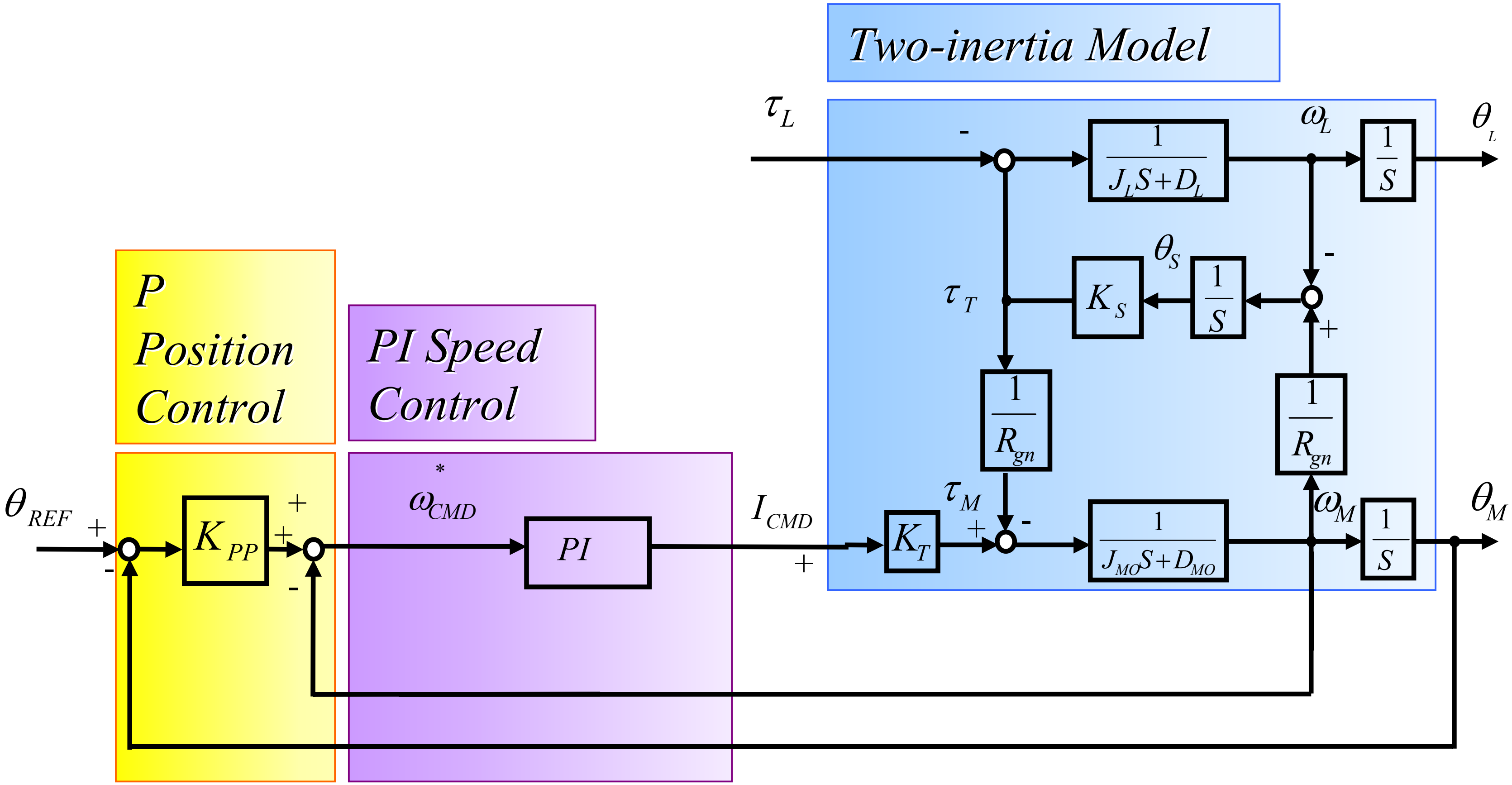
Problem

1.Vibration Suppression

2. Improve speed response

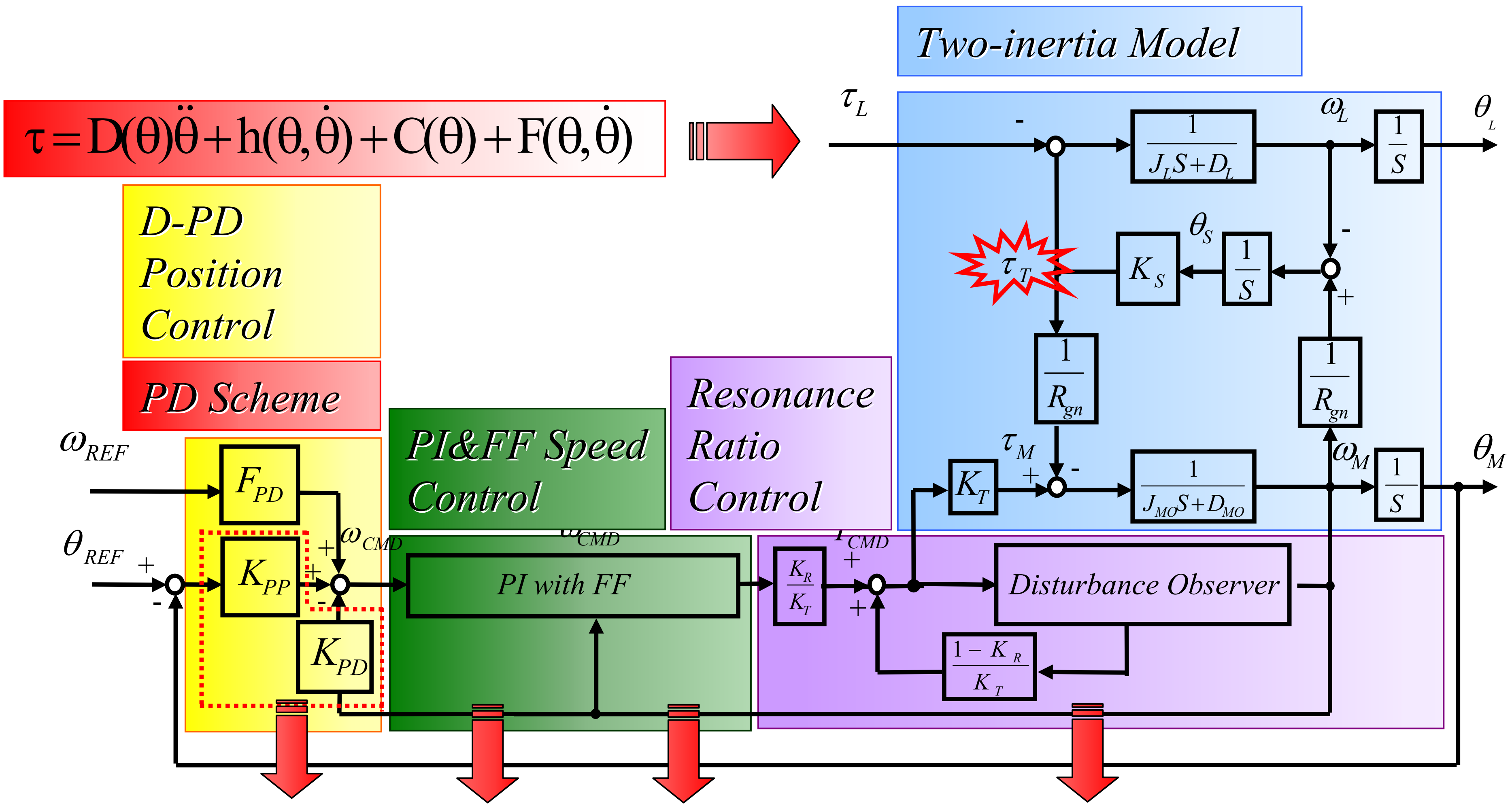
3. Reduce the state error of position control

Outline of conventional control method



Outline of proposed control method

$$\tau = D(\theta)\ddot{\theta} + h(\theta,\dot{\theta}) + C(\theta) + F(\theta,\dot{\theta})$$



Reduce the state error of position control

Improve speed response

Vibration Suppression & Disturbance Rejection

Three Degree of Freedom of Robot Manipulator

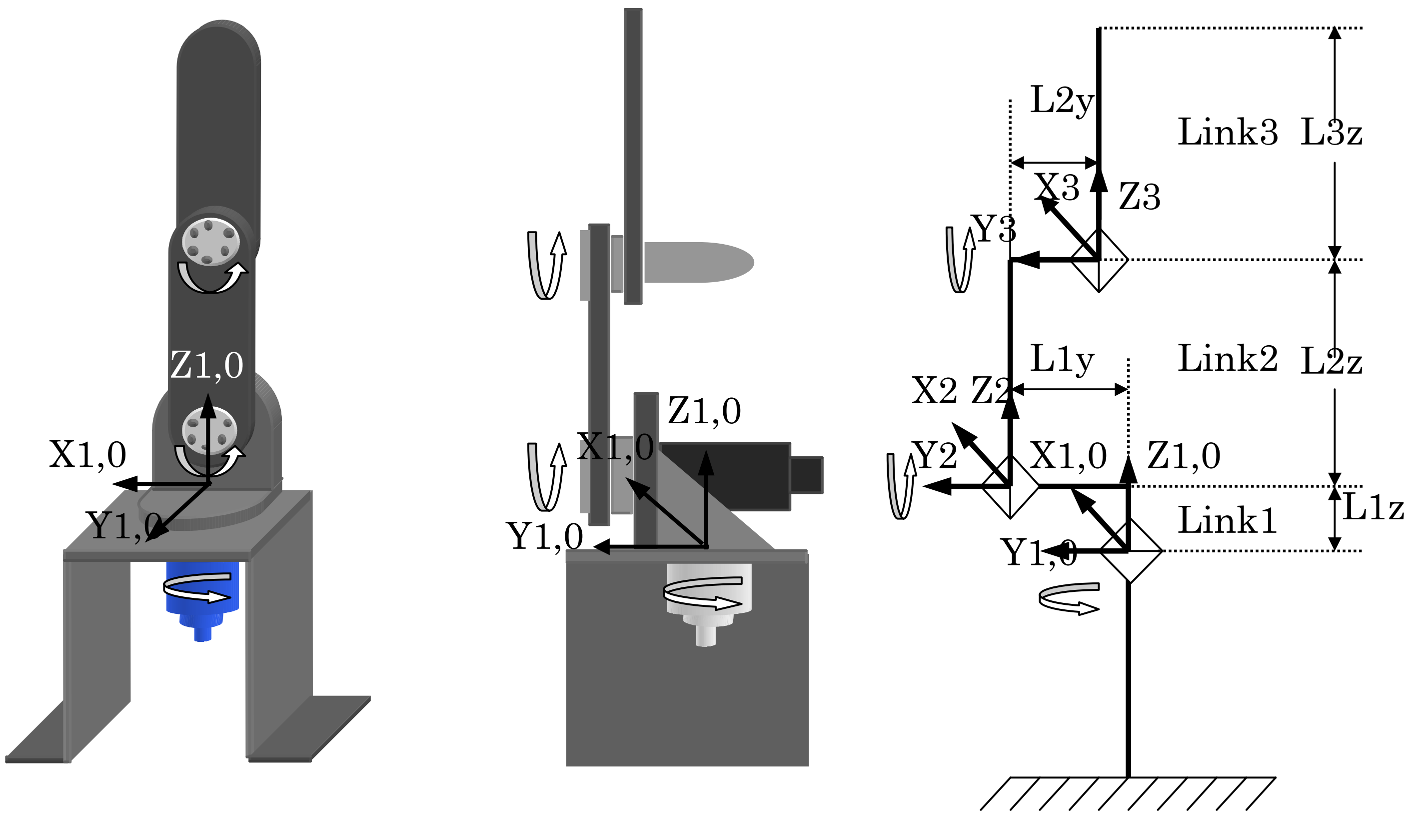
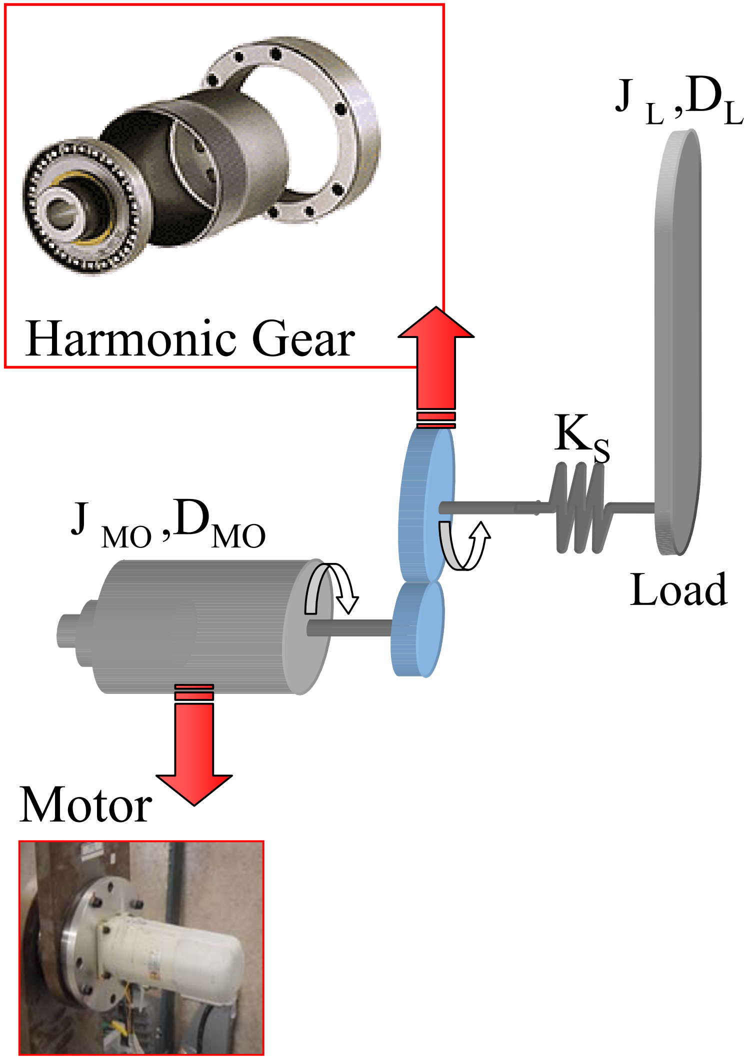


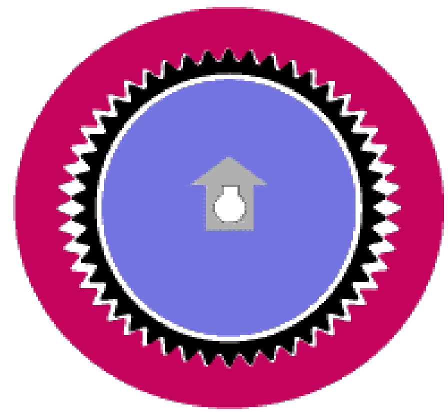
Figure 1:Description of the position and orientation of the end-effecter frame

Two-Inertia Model



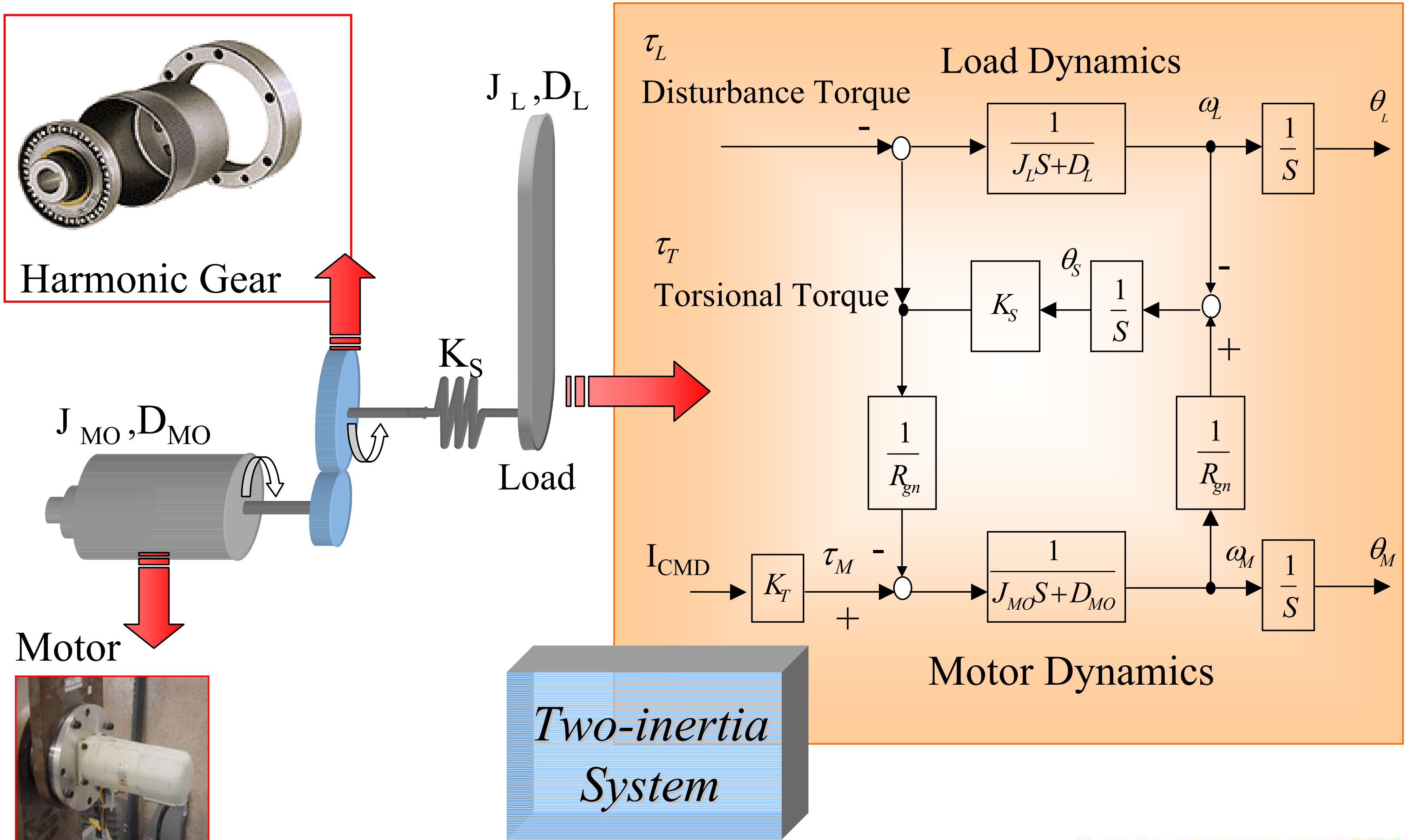
Advantages

- Positioning accuracy and repeatability
- Not back-drivable
- Zero-Backlash
- High efficiency



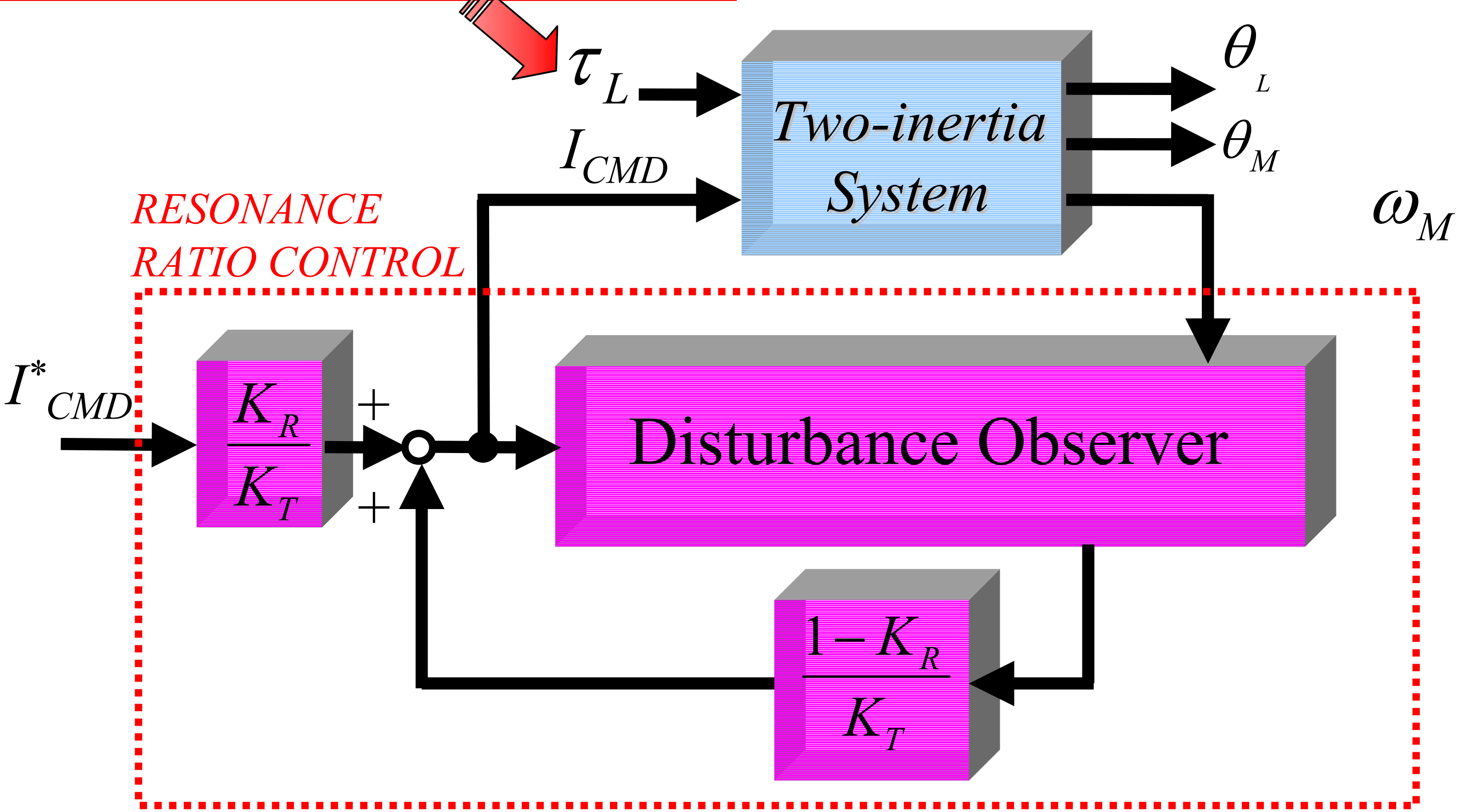
Motor in Motion Simulation

Two-Inertia Model



Resonance ratio control

$$\tau = D(\theta)\ddot{\theta} + h(\theta,\dot{\theta}) + C(\theta) + F(\theta,\dot{\theta})$$



Resonance ratio control and PI Speed Control

The resonance frequency of the new system is changed to

$$J_M = \frac{J_{MO}}{K_R} \quad \Longrightarrow \quad \omega_r = \sqrt{\frac{K_s}{J_L}\left(1 + \frac{J_L K_R}{J_{MO} Rgn^2}\right)}$$

Changed Resonance Frequency to

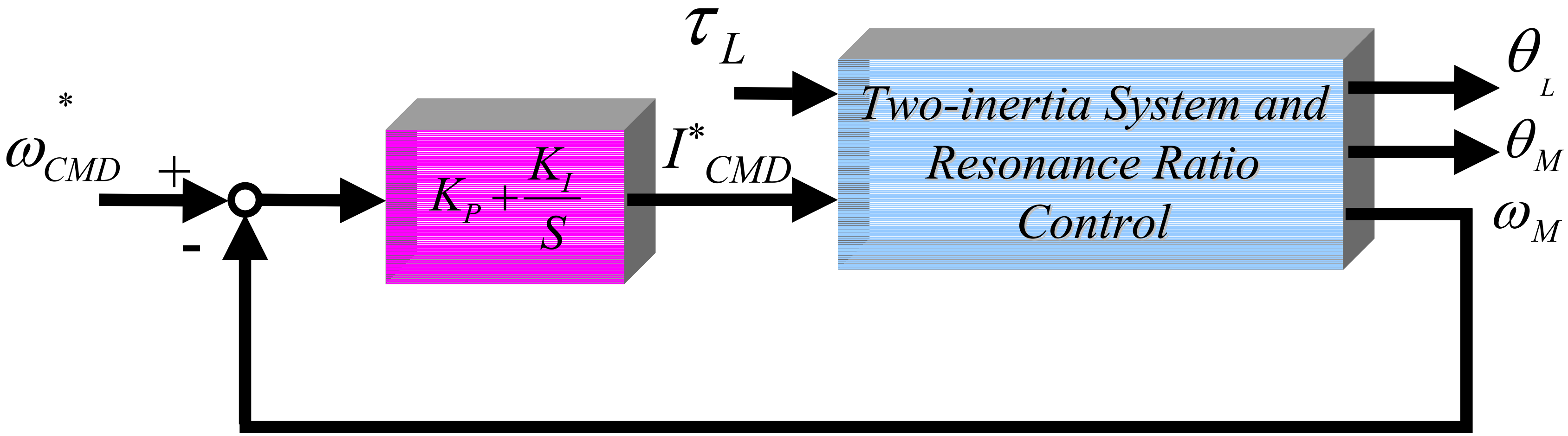
The resonance ratio can be controlled by K_R

$$H = \frac{\omega_r}{\omega_a} = \sqrt{1 + \frac{J_L K_R}{J_{MO} Rgn^2}}$$

Optimal Resonance Ratio

Determined by CDM method

Resonance ratio control and PI Speed Control



Resonance ratio control and PI Speed Control

Manabe's Model Polynomial

$$\tau = \frac{a_1}{a_0} = \frac{K_P}{K_I} = \frac{1}{\beta} \qquad \gamma_1 = \frac{a_1^2}{a_0 a_2} = 2.5, \quad \gamma_2 = \frac{a_2^2}{a_1 a_3} = 2, \quad \gamma_3 = \frac{a_3^2}{a_2 a_4} = 2$$

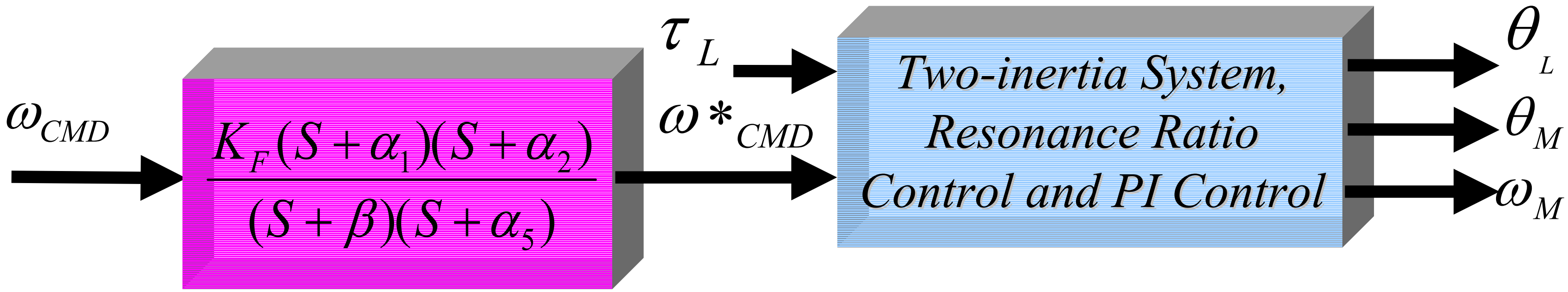
K_I, K_P and K_R Determined by CDM method

$$H = \frac{4\sqrt{5}}{5}, \qquad K_I = \frac{4K_S}{11 K_T R g n^2}, \quad K_P = \sqrt{\frac{(2 \times 16^2 + 40 J_L) K_S}{11^2 K_T^2 R g n^4}}$$

Optimal Resonance Ratio

$$K_R = \frac{H^2 - 1}{R_O}$$

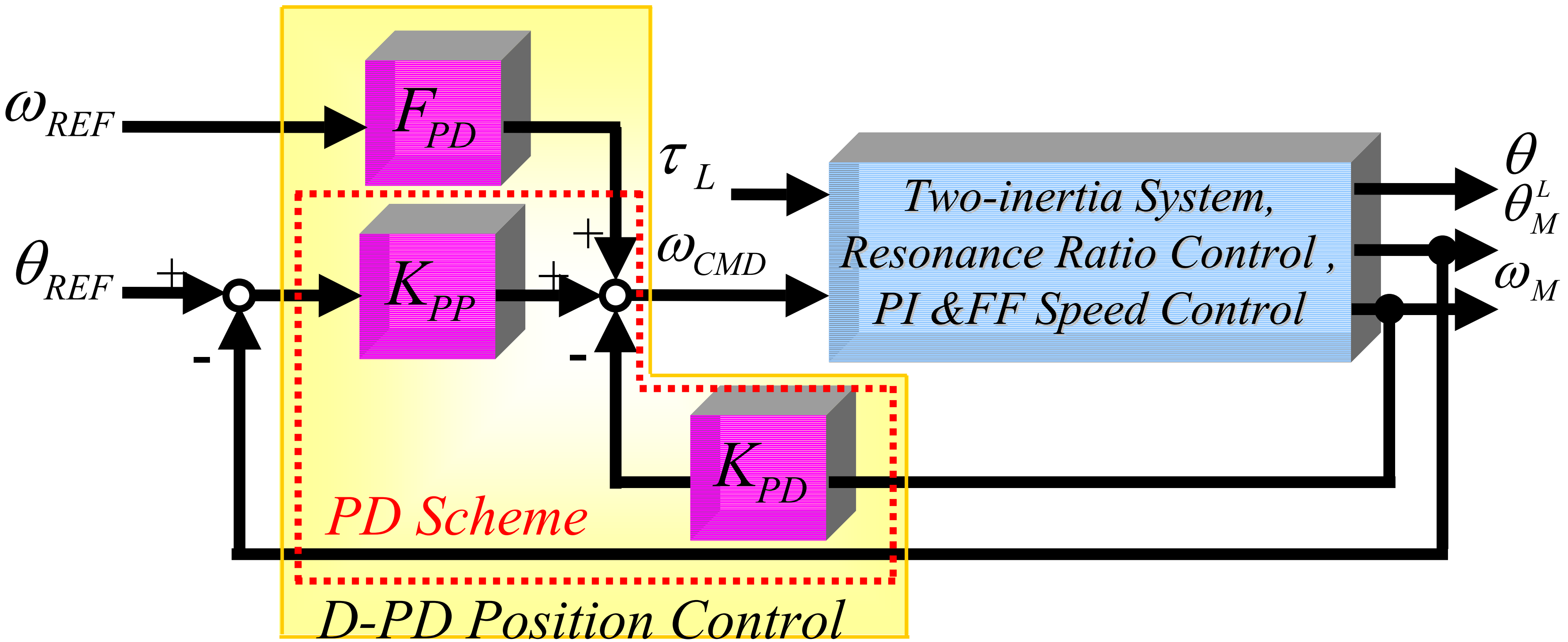
Feedforward Compensator



Feedforward Controller

Eliminate effects of dominant poles $-\alpha_1, -\alpha_2$ ⇒ High Speed Response

D-PD Position Control



D-PD Position Control

Manabe's Model Polynomial

$$\tau = \frac{aa_1}{aa_0} = \frac{K_P}{K_I} = \frac{1}{\beta}$$ *Equivalent time constant*

$$\gamma_1 = \frac{aa_1^2}{aa_0 aa_2} = 2.5$$ *Stability index*

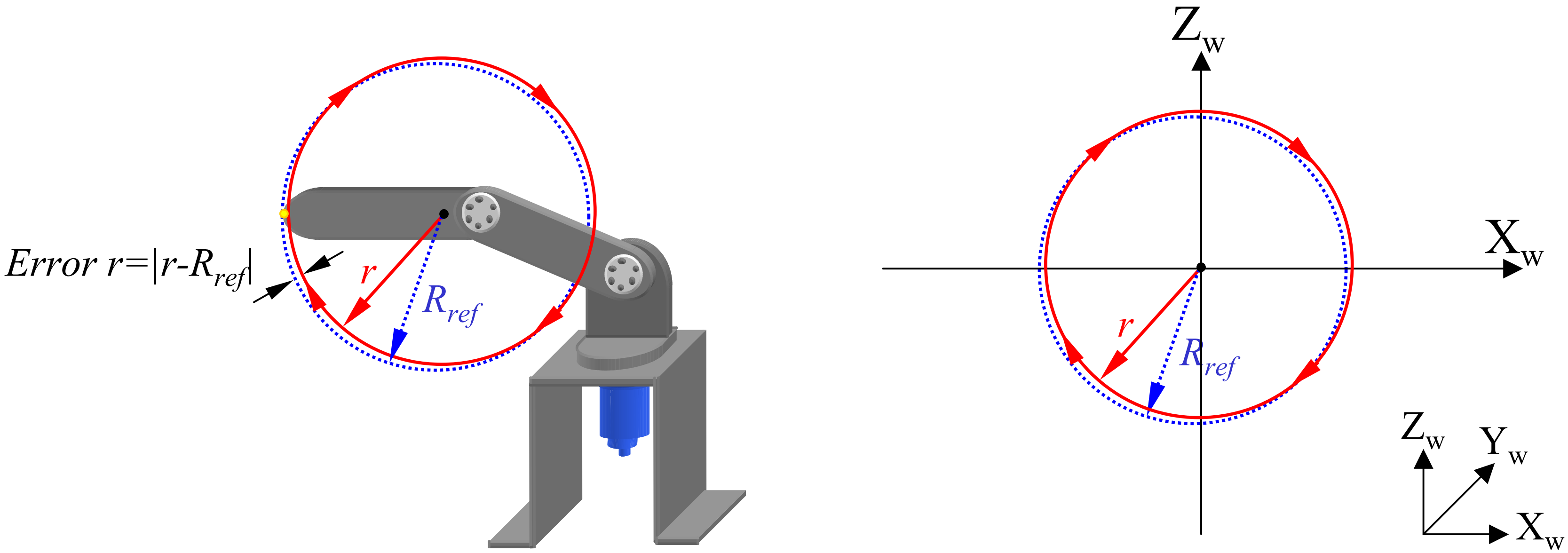
K_{PD} and K_{PP} Determined by CDM method

$$\begin{bmatrix} K_{PD} \\ K_{PP} \end{bmatrix} = \begin{bmatrix} K_{add}K_S & K_{add}D_L - \dfrac{K_S K_{add}}{\beta} \\ K_{add}K_S - K_{add}D_L\beta\gamma_1 & K_{add}D_L - K_{add}J_L\beta\gamma_1 \end{bmatrix}^{-1} \begin{bmatrix} -\alpha_3\alpha_4\alpha_5 J_L \\ \alpha_3\alpha_4 J_L\beta\gamma_1 + \alpha_4\alpha_5 J_L\beta\gamma_1 + \alpha_3\alpha_5 J_L\beta\gamma_1 - \alpha_3\alpha_4\alpha_5 J_L \end{bmatrix}$$

F_{PD} Determined by arbitrary zero $-z_1$

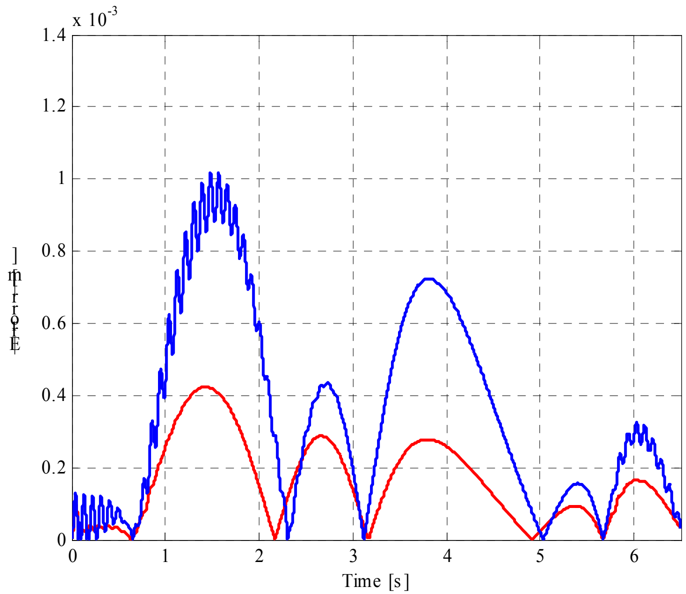
$$F_{pd} = \frac{K_{pp}}{z_1}$$

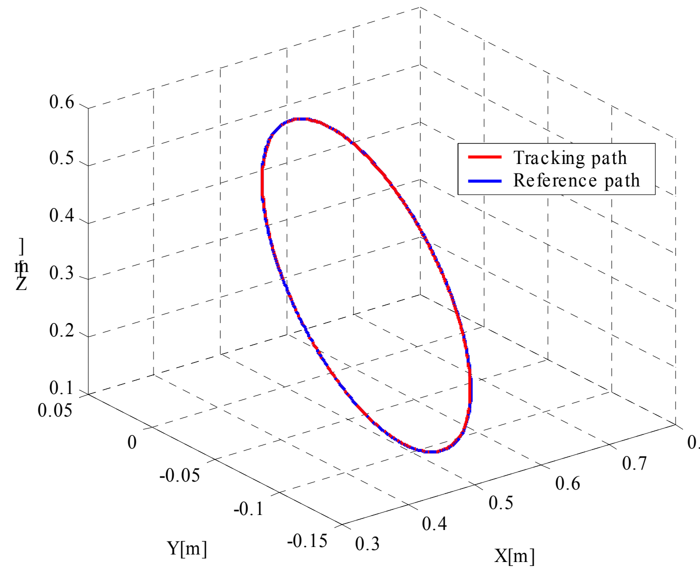
Simulation Results



The three-dimensional circle trajectory path which rotating angle from X-axis 45° and from Z-axis 45°

Simulation Results





Controller	*Maximum Error*	*Area of Error*
Resonance Ratio Control , PI &FF Speed Control and D-PD Position Control	*0.42 mm*	*0.0010 m-s*
PI Speed Control and P Position Control	*1.10mm*	*0.0023 m-s*

Conclusion

1. Vibration Suppression : Resonance Ratio Control and PI Speed Controller

2. Improve speed response: Feedforward control

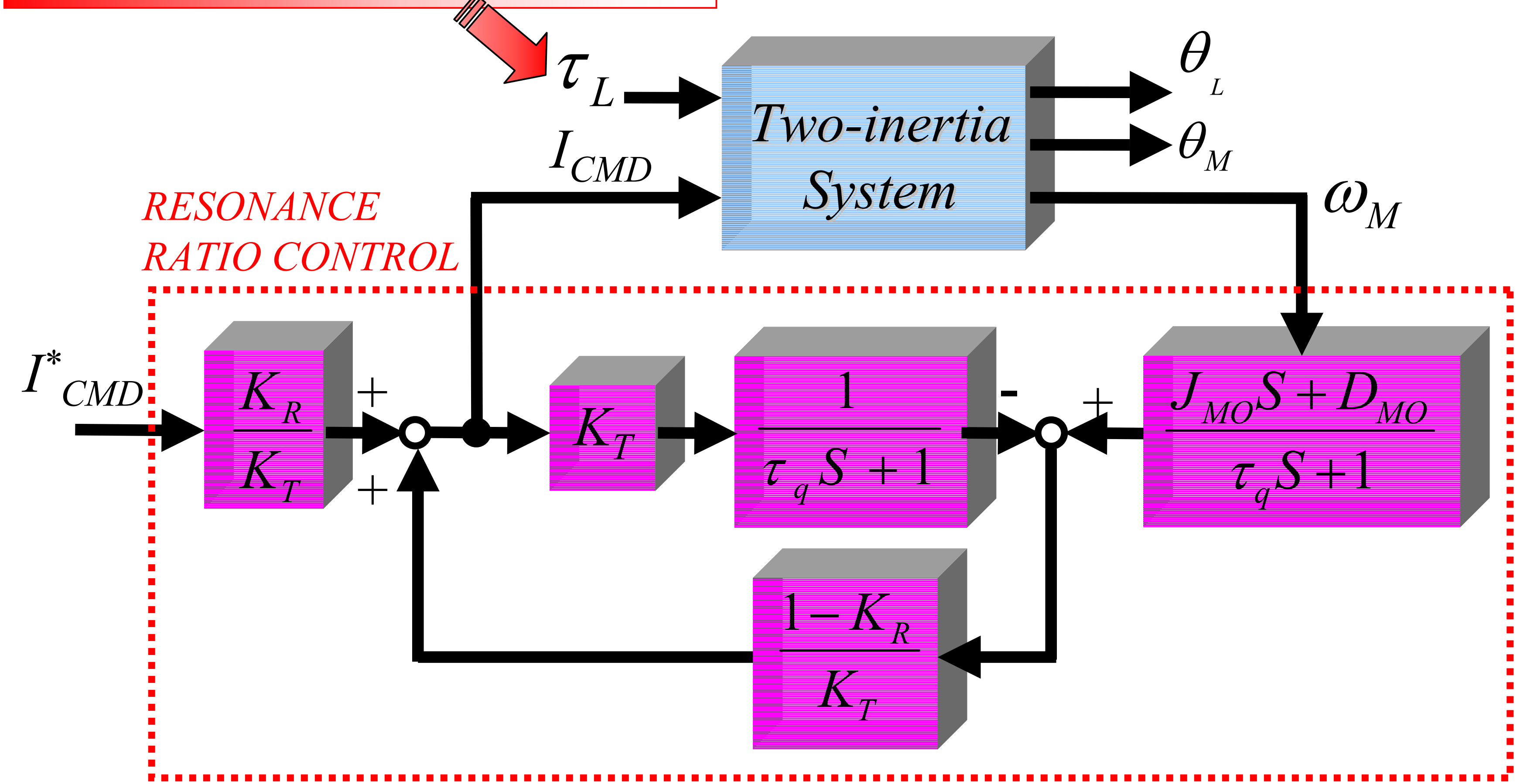
3. Reduce the state error of position control : D-PD Position Controller

4. All of this controller designed by CDM method, considering from stability index and rise time.

Thank you

Resonance ratio control

$$\tau = D(\theta)\ddot{\theta} + h(\theta,\dot{\theta}) + C(\theta) + F(\theta,\dot{\theta})$$



Dynamic of Robot Manipulator

$$\tau = D(\theta)\ddot{\theta} + h(\theta,\dot{\theta}) + C(\theta) + F(\theta,\dot{\theta})$$

$$\begin{bmatrix}\tau_1\\ \tau_2\\ \tau_3\end{bmatrix} = \begin{bmatrix}D_{11} & D_{12} & D_{13}\\ D_{21} & D_{22} & D_{23}\\ D_{31} & D_{32} & D_{33}\end{bmatrix}\begin{bmatrix}\ddot{\theta}_1\\ \ddot{\theta}_2\\ \ddot{\theta}_3\end{bmatrix} + \begin{bmatrix}h_{11} & h_{12} & h_{13}\\ h_{21} & h_{22} & h_{23}\\ h_{31} & h_{32} & h_{33}\end{bmatrix}\begin{bmatrix}\dot{\theta}_1^{2}\\ \dot{\theta}_2^{2}\\ \dot{\theta}_3^{2}\end{bmatrix} + \begin{bmatrix}hc_{11} & hc_{12} & hc_{13}\\ hc_{21} & hc_{22} & hc_{23}\\ hc_{31} & hc_{32} & hc_{33}\end{bmatrix}\begin{bmatrix}\dot{\theta}_1\dot{\theta}_2\\ \dot{\theta}_2\dot{\theta}_3\\ \dot{\theta}_1\dot{\theta}_3\end{bmatrix} + \begin{bmatrix}C_1\\ C_2\\ C_3\end{bmatrix} + \begin{bmatrix}F_1\\ F_2\\ F_3\end{bmatrix}$$

- Acceleration-relate symmetric matrix term
- Nonlinear Coriolis and centrifugal force vector term
- Gravity loading force vector term
- Coulomb and viscous friction term