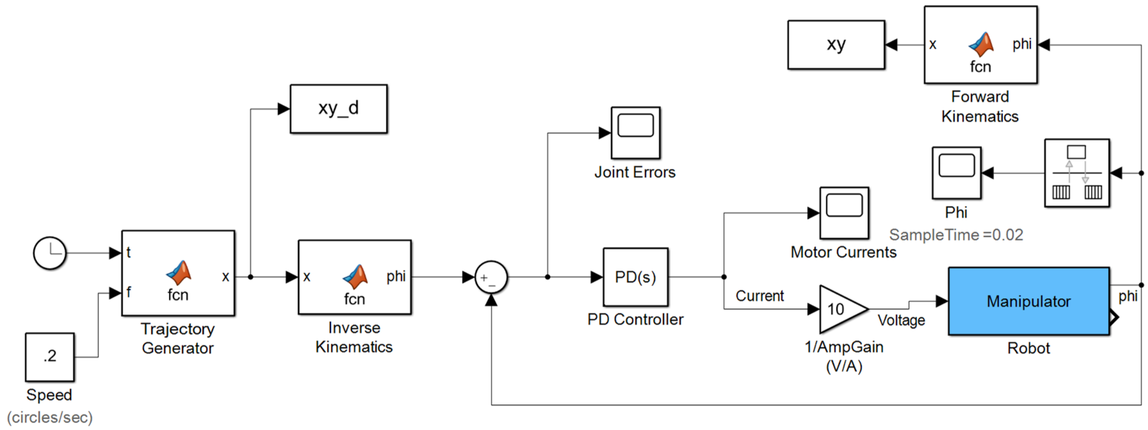
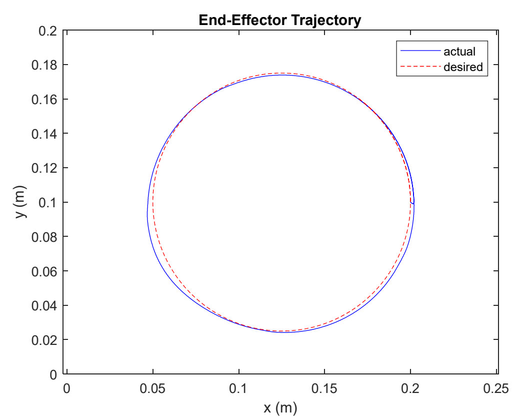
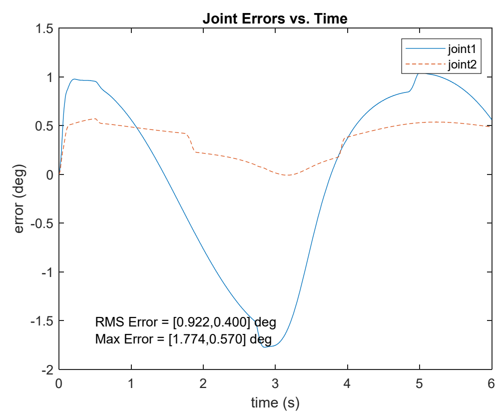
Problem 1: Decentralized Control

1.1 PD Control Only

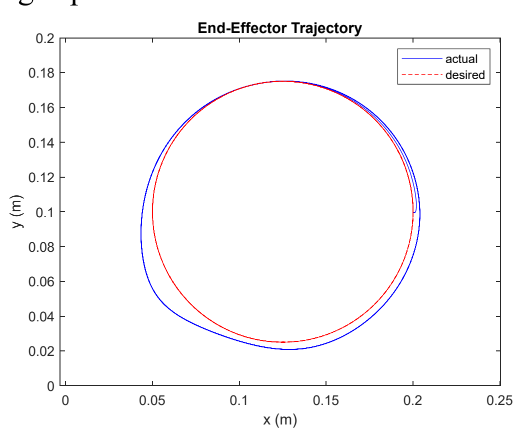


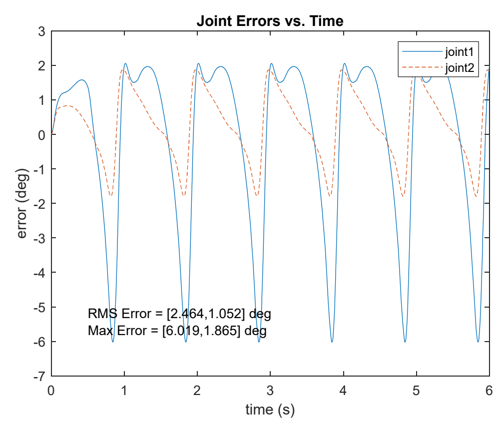
Low speed:





High speed:

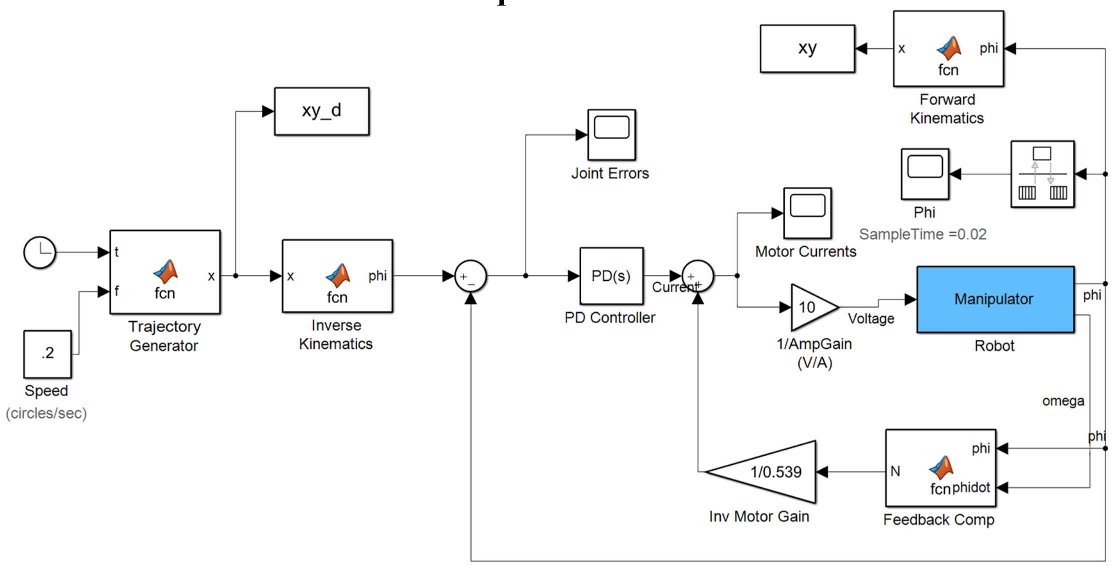




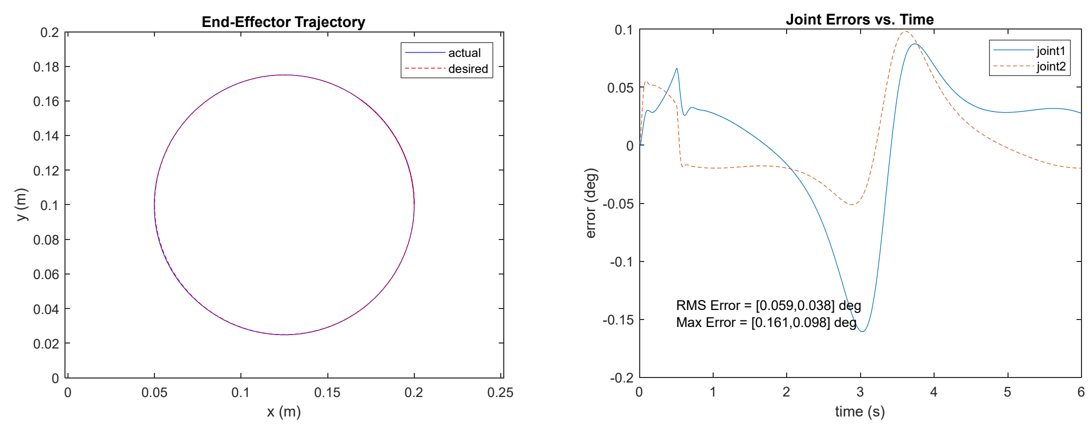
Gains of Kp = 8 and Kd = 0.27 were used from PS#4. The joint errors were less than 2 degrees at low speed. At high speed the errors are significantly worse. Note that these results were obtained using the Simulink ODE3 solver and a sample time of 0.002s. Results will vary for different solvers and/or sample times.

© Stephen Mascaro, Associate Professor, University of Utah
Unauthorized reproduction of this material is expressly forbidden

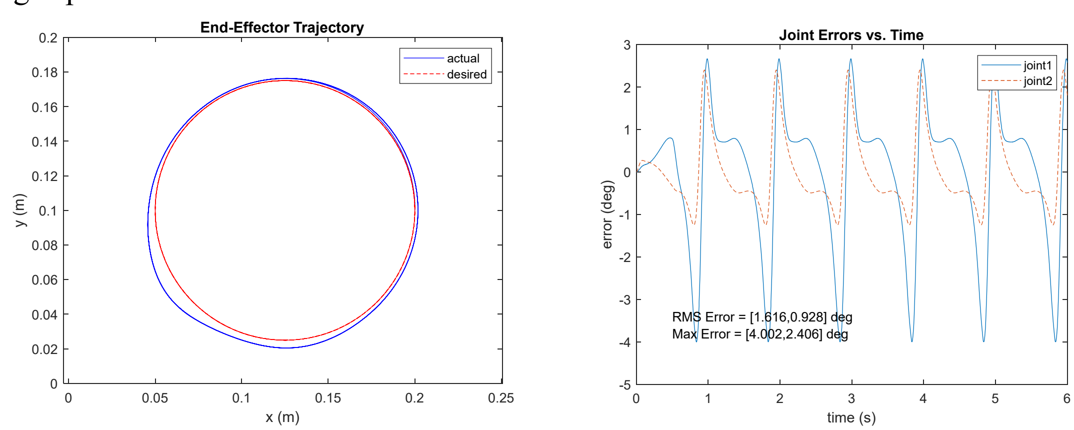
1.2 PD with nonlinear feedback compensation



Low speed:



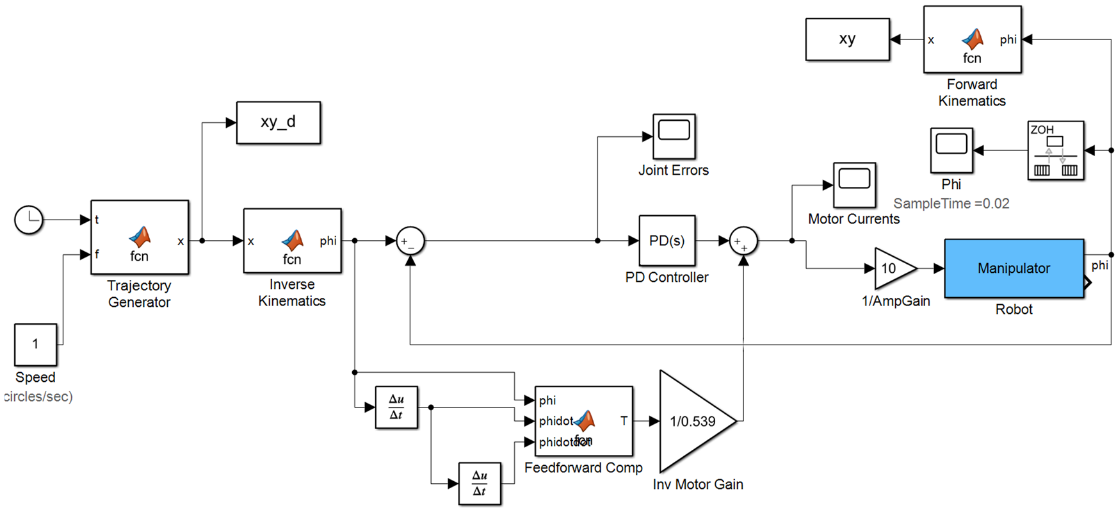
High speed:



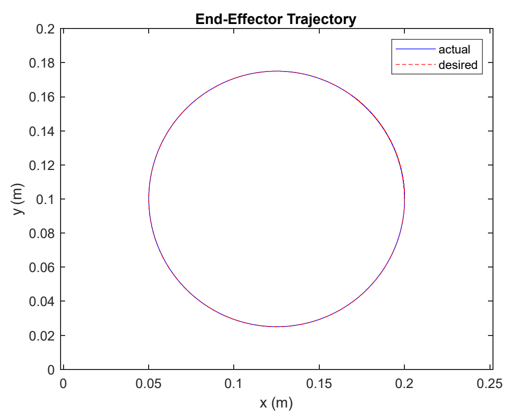
The addition of nonlinear feedback compensation does very well at low speed, decreasing the errors by a factor of 10, but offers only a small improvement at high speed.

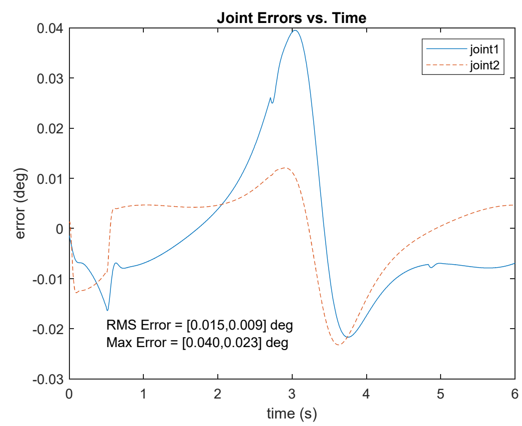
© Stephen Mascaro, Associate Professor, University of Utah
Unauthorized reproduction of this material is expressly forbidden

1.3 Feedforward Computed Torque Control

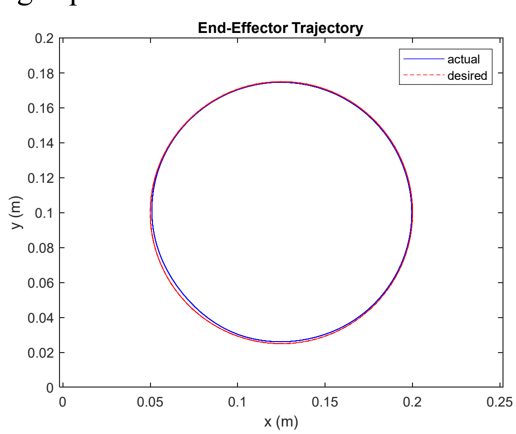


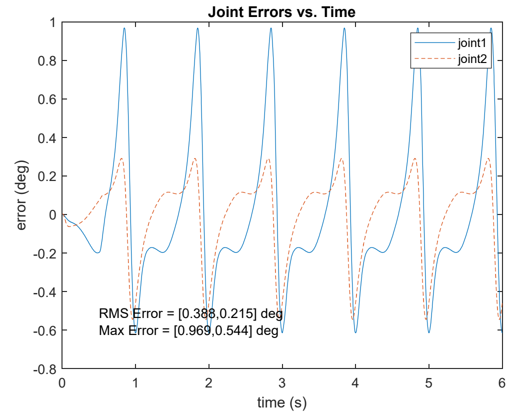
Low speed:





High speed:

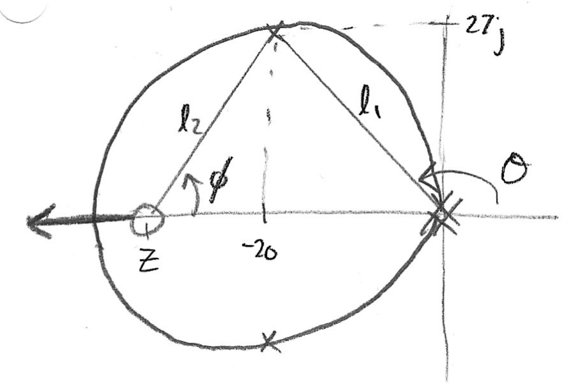




The feedforward compensation does significantly better than the feedback compensation since it includes inertia compensation. The tracking errors are almost an order of magnitude smaller at both low and high speed.

© Stephen Mascaro, Associate Professor, University of Utah
Unauthorized reproduction of this material is expressly forbidden

2.1 PD control: Design for 10% O.S. and $T_s = 0.2s$



want closed loop poles at $s = -20 \pm 27j$ as in PS #4

$$G_c G_p = \frac{K_p + K_D s}{s^2} = \frac{K_D (s + K_p/K_D)}{s^2}$$

loop gain

Angle Condition: $\phi - 2\theta = \pm 180°$

$$\phi = \pm 180° + 2\tan^{-1}\left(\frac{27}{-20}\right) = \pm 180 + 2(126°) = 72°$$

$$\tan 72° = \frac{27}{-20 - z} \qquad z = -20 - \frac{27}{\tan 72°} = -29$$

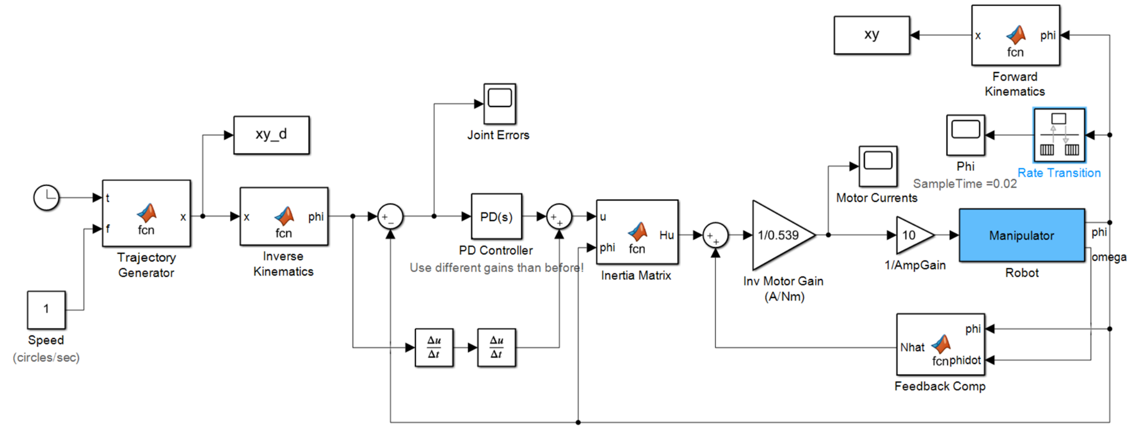
So place zero at $s = -29$ $\quad \frac{K_p}{K_D} = 29$

Magnitude Condition:

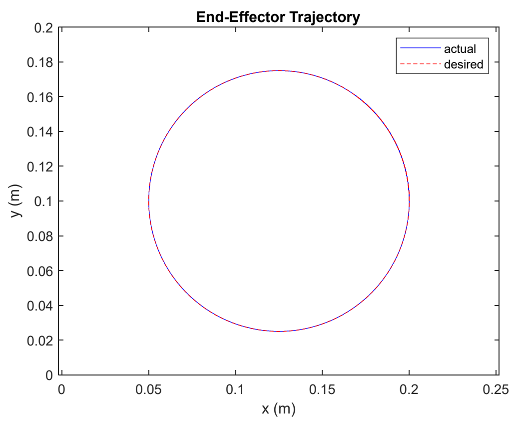
$$K_D = \frac{l_1^2}{l_2} = \frac{27^2 + 20^2}{\sqrt{27^2 + 9^2}} = 40$$

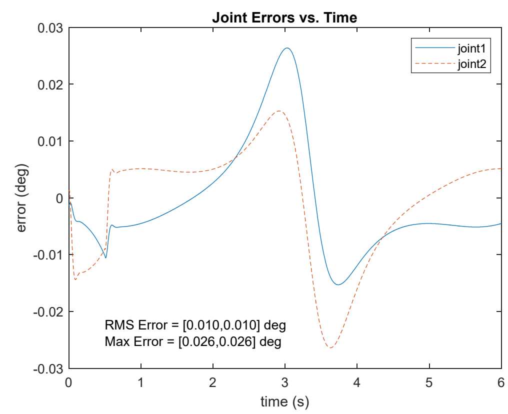
$$K_p = 40 \cdot 29 = 1200$$

Problem 2.2: Inverse Dynamics Control

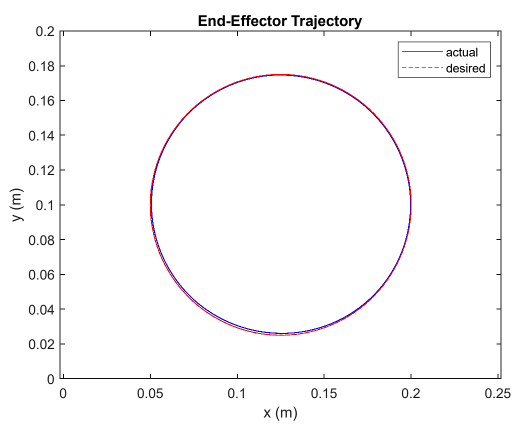


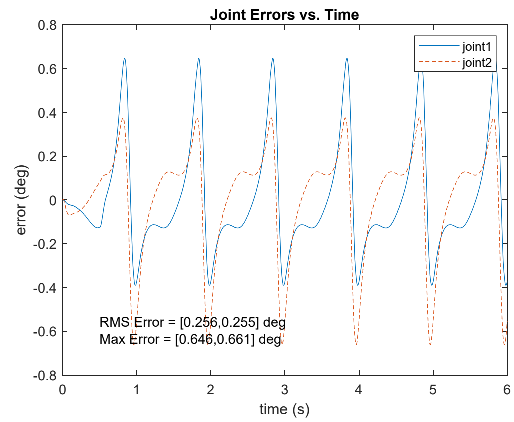
Low speed:





High speed:





The inverse dynamics control does best of all since it not only linearizes, but decouples the influence of the controller on the joints. Note that we are now using different PD gains, as designed in 2.1. Another way to justify this is that we need to raise the PD gains by about a couple orders of magnitude, since the output of the PD controller is now multiplied by the inertia matrix and inverse motor gain.

© Stephen Mascaro, Associate Professor, University of Utah
Unauthorized reproduction of this material is expressly forbidden