Warsaw University of Technology

FACULTY OF
POWER AND AERONAUTICAL ENGINEERING

Institute of Automation and Robotics

Homework 2

in the subject of Modelling and control of manipulator

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student record book number 323834

submitted to

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Given Data – homework 2 (no. 11)

J_m = 5.5e–4 kg.m2;
K_b = 0.105 V/(rad/s);
K_m = 0.105 N.m/A;
L = 0.9 e-3 H;
R = 0.76 Ω;
B_m = 4e–4 N.m/(rad/s);
gear ratio r=156;
under saturation limits of the manipulator input signal: V_{min} = –35 V, V_{max} = 35 V.
τ_l/r = 2 N.m
ω_{ref} = α /4 [rad/s]
maximal control error between 0.01 and 0.005
t_b = $0.2t_m$
trajectory from $\theta_0 = 0$ to $\theta_f = 0.5$

The trajectory equation used are shown as follows

Cubic trajectory equation

$$q(t) = \begin{cases} 1.5t^2 - t^3, & t \leq 1 \\ 0.5, & else \end{cases}$$

LSPB trajectory equation

$$q(t) = \begin{cases} 1.5625t^2, & t \leq 0.2 \\ 0.0625 + 0.625(\mathrm{t} - 0.2), & 0.2 \leq t \leq 0.8 \\ 0.5 - 1.5625(t - 0.6)^2, & 0.1 \leq t \leq 1 \\ 0.5, & else \end{cases}$$

1 Model of a single–link manipulator

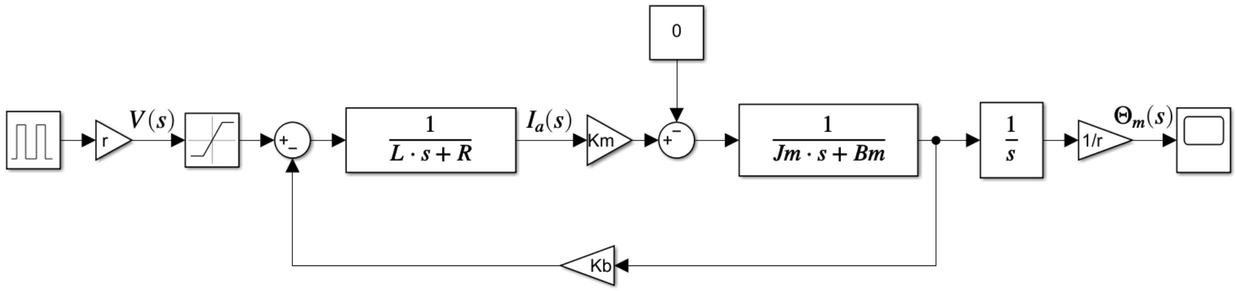

Figure 1 Accurate Model

2 Simplified model neglecting the electrical time constant

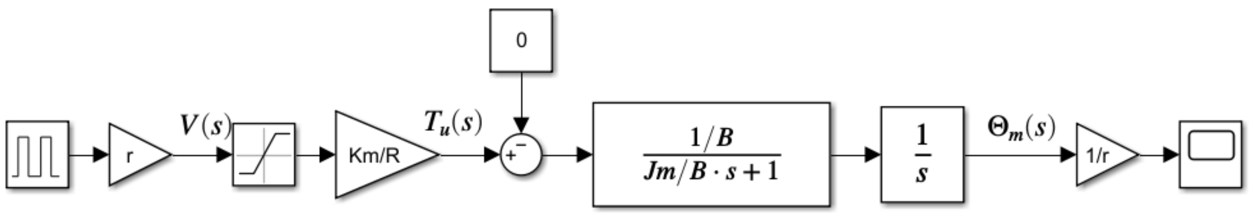

Figure 2 Simplified Model

2.1 Comparison and difference plotting

2.1.1 Comparisons plotting

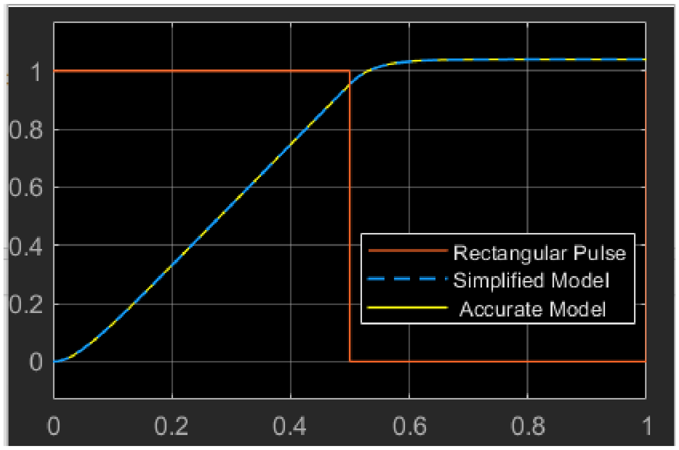

Figure 3 Accurate vs Simplified Model

2.1.2 Difference plotting

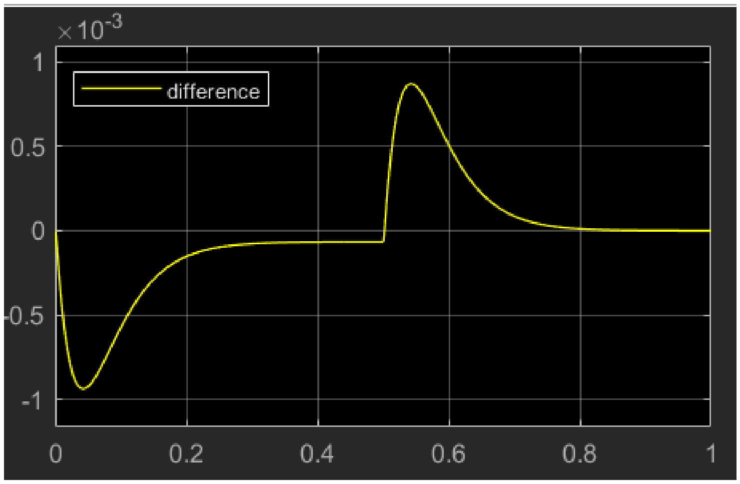

Figure 4 Accurate vs Simplified Model(Difference)

3 PD control system model for cubic reference trajectory

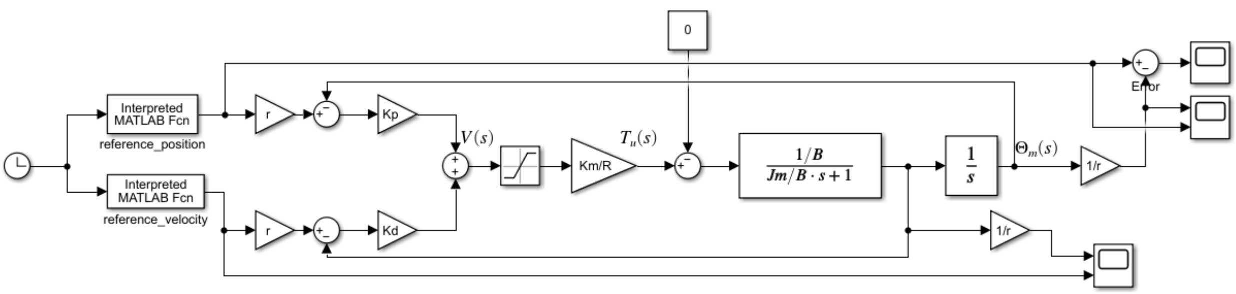

Figure 5 PD Model

Tuning PID by the choice of ω

$\omega = 40, \quad Kp = 8.0614, \quad \text{Kd} = 0.2504$

$\omega = 50, \quad Kp = 9.9524, \quad Kd = 0.2902$

$\omega = 60, \quad Kp = 14.3314, \quad Kd = 0.3698$

Figure 6 PD Control error for PD model with cubic reference trajectory

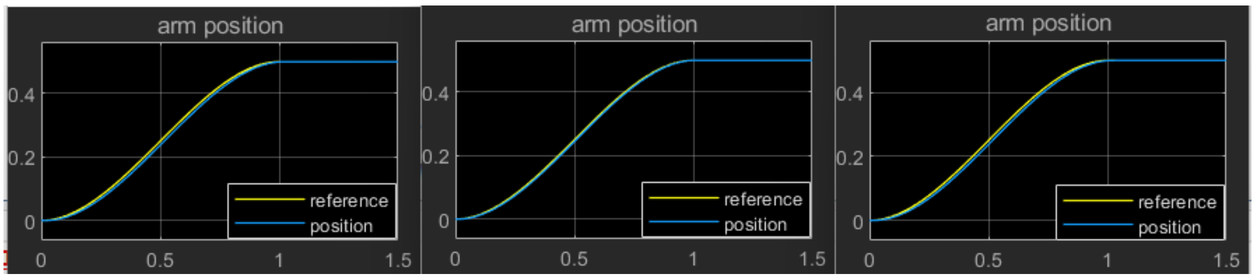

Figure 7 PD Arm position for PD model with cubic reference trajectory

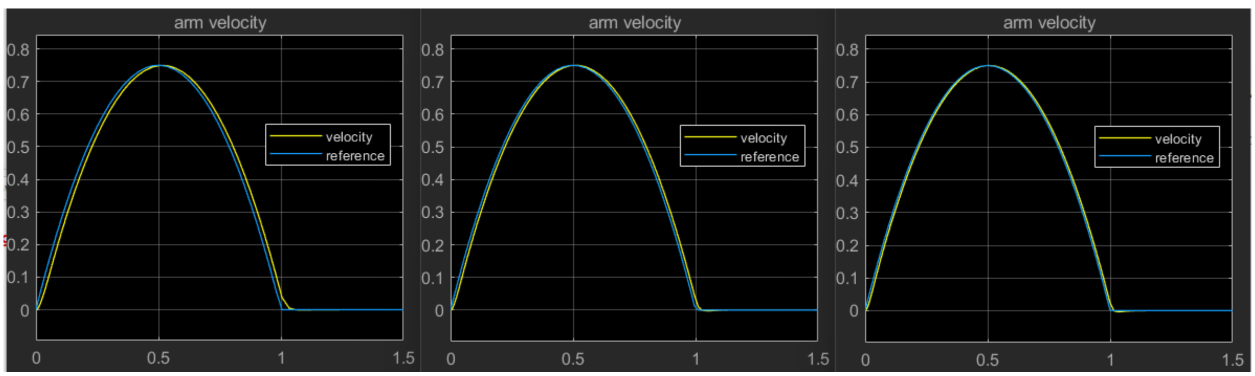

Figure 8 PD Arm velocity for PD model with cubic reference trajectory

After comparing the $\omega = 50$ is chosen because the required threshold value is reached. However further increasing ω increases proportional gain and derivative gain but further increasing ω will decrease the robustness of the control system

3.1 Behavior of system to step-change of the constant reference trajectory

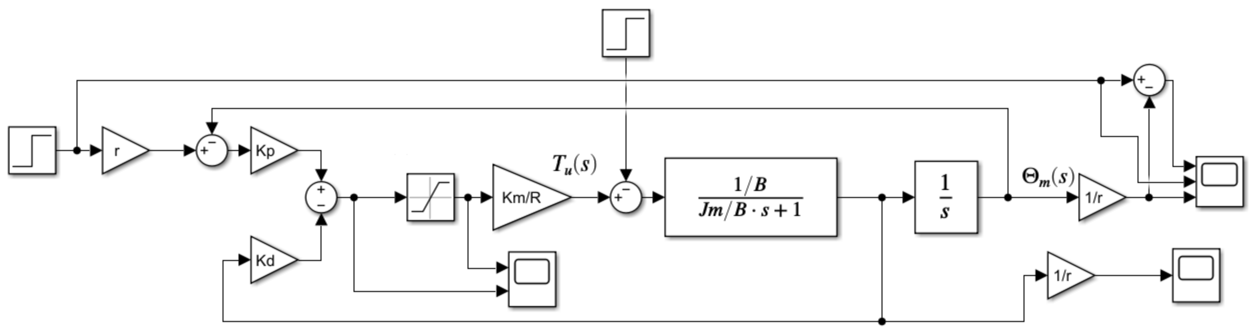

Figure 9 Modified P-D Model with step-change of constant reference trajectory

3.1.1.1 Position Error and Arm position

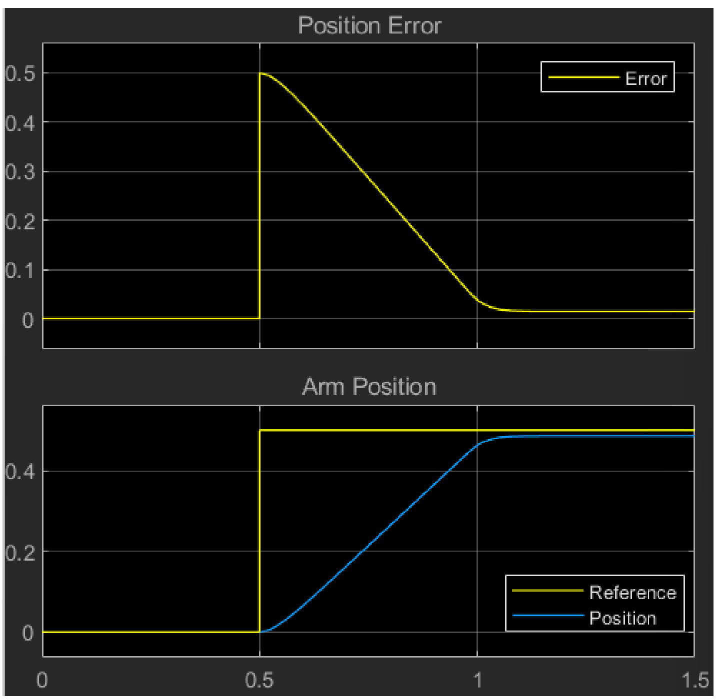

Figure 10 Modified P-D Model Position Error and Arm Position

3.1.1.2 PD output and Manipulator input

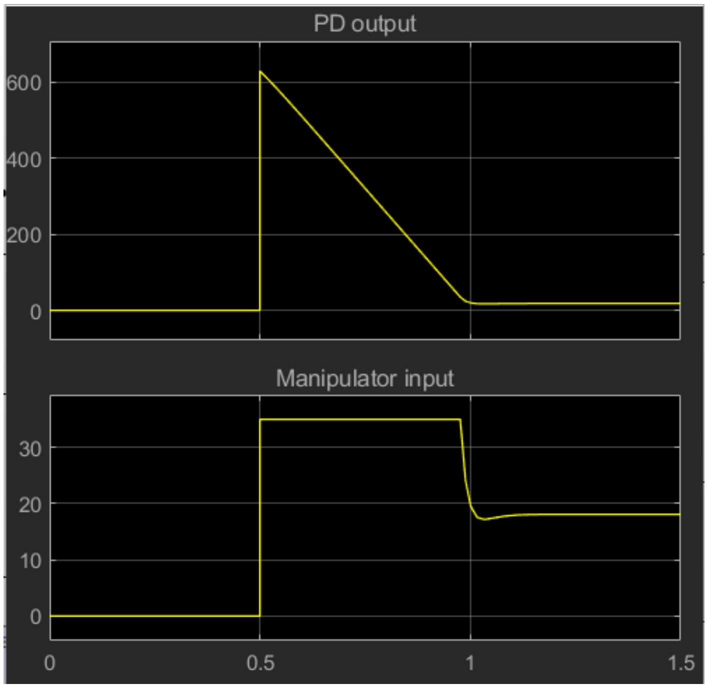

Figure 11 Modified P-D Model Position PD output and manipulator input

3.1.1.3 Arm velocity

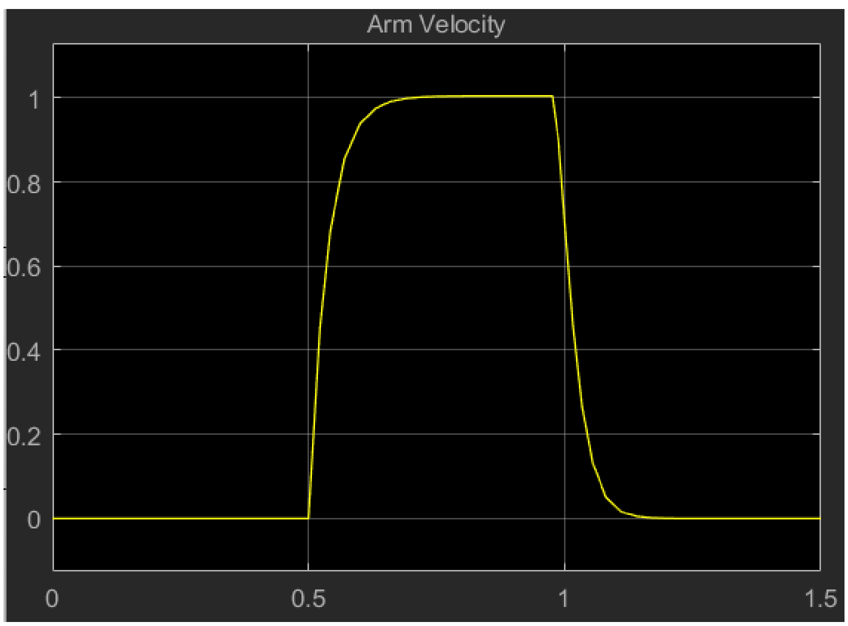

Figure 12 Modified P-D Model Arm Velocity

4 PD control system model for LSPB reference trajectory

4.1.1.1 Position Error

Figure 13 PD Control error for PD model with LSBP reference trajectory

4.1.1.2 Arm position

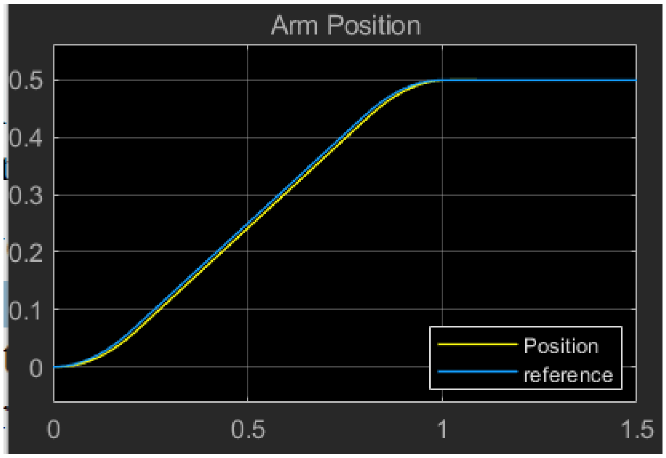

Figure 14 Arm Position for PD model with LSBP reference trajectory

4.1.1.3 Arm velocity

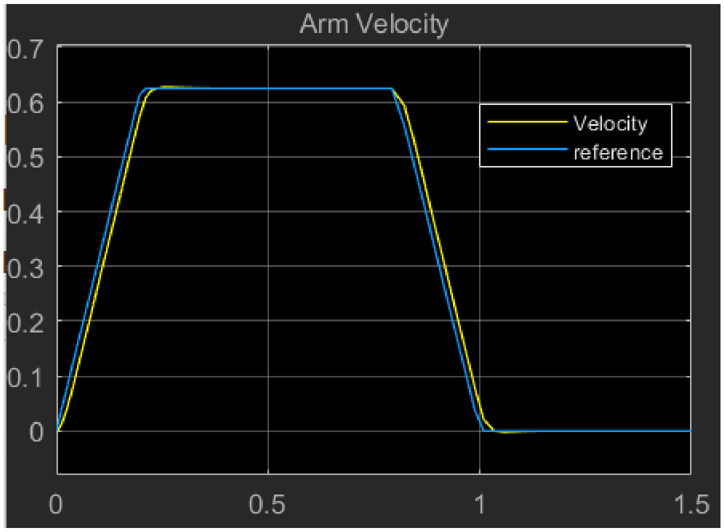

Figure 15 Arm Velocity for PD model with LSBP reference trajectory

5 Influence of the constant load disturbance

Now the designed PD model is checked under the influence of constant load of 2Nm

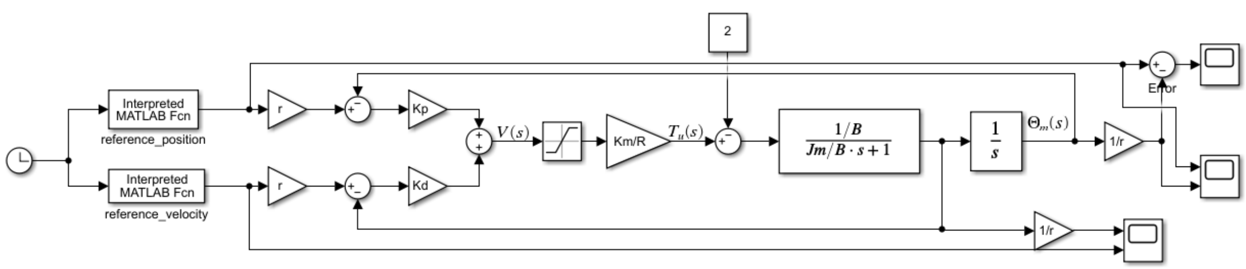

Figure 16 PD Model with load disturbance of 2Nm

5.1 For cubic reference trajectories

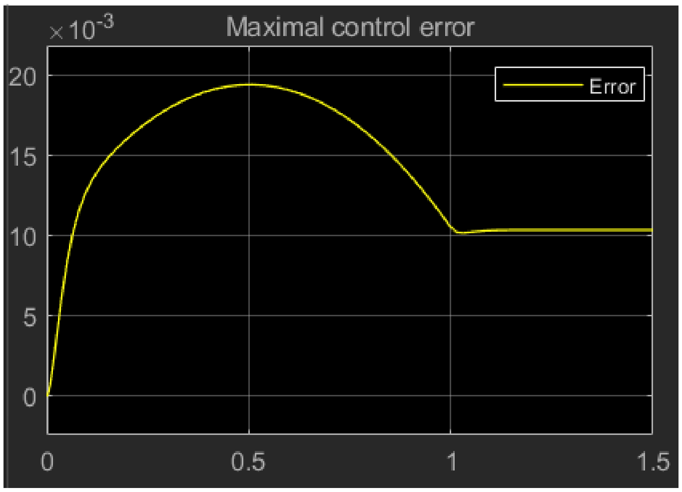

Figure 17 Control error for PD model with cubic reference trajectory with load disturbance

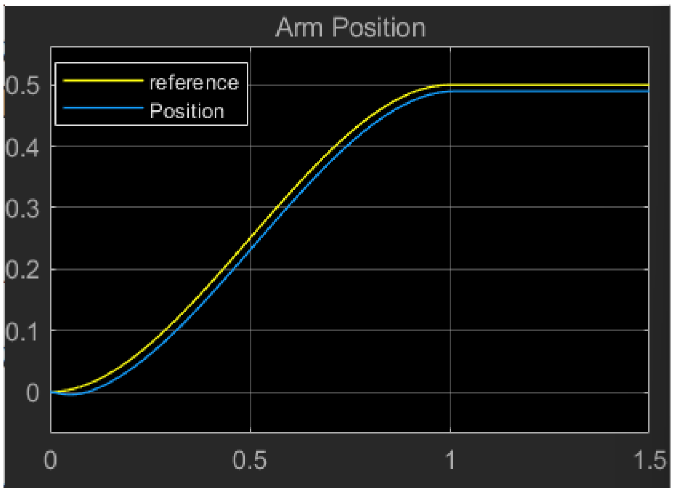

Figure 18 Arm position for PD model with cubic reference trajectory with load disturbance

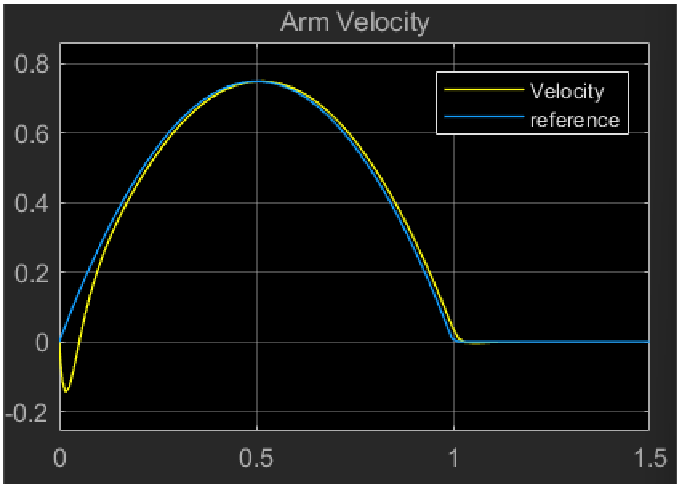

Figure 19 Arm velocity for PD model with cubic reference trajectory with load disturbance

After seeing the plots with the disturbance value. It is seen that now the error has passed the Maximal control error of 0.01. The system now also has the steady state error that is greater than the desired Maximal control error of 0.01. Thus the control should not be done. And ω should be Increased.

5.2 For LSPB reference trajectories

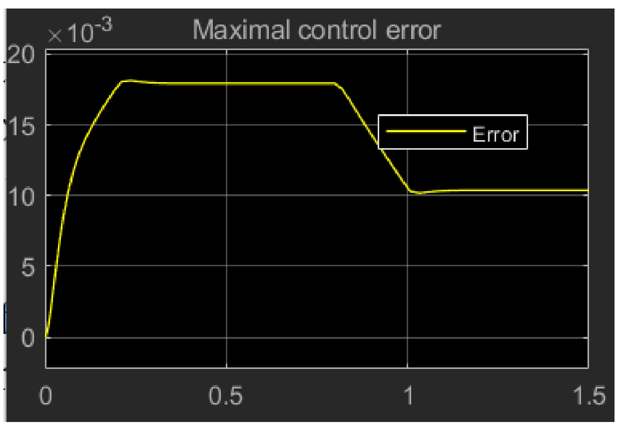

Figure 20 Control error for PD model with LSPB reference trajectory with load disturbance

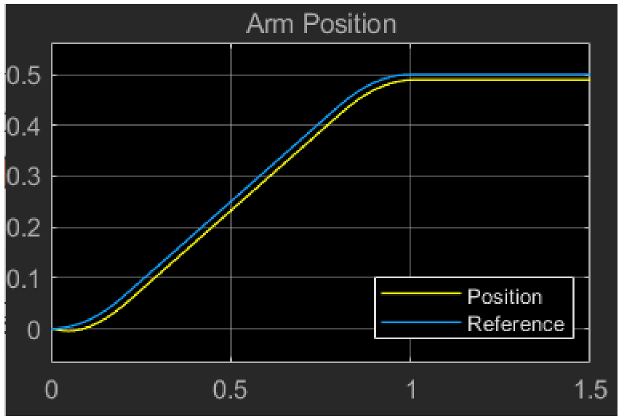

Figure 21 Arm position for PD model with LSPB reference trajectory with load disturbance

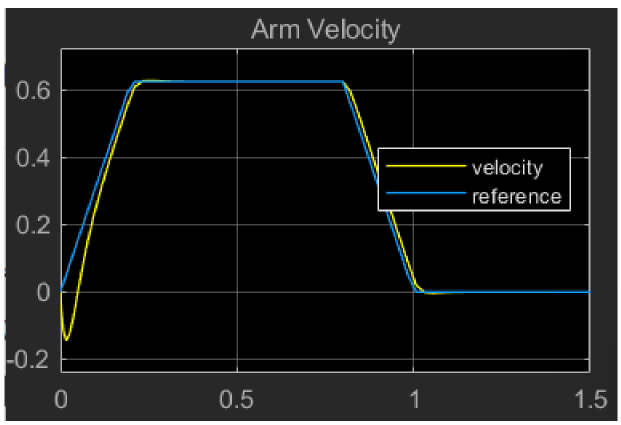

Figure 22 Arm velocity for PD model with LSPB reference trajectory with load disturbance

After seeing the plots with the disturbance value. It is seen that now the error has passed the Maximal control error of 0.01. The system now also has the steady state error that is greater than the desired Maximal control error of 0.01. Thus the control should not be done.

6 Design of PID control system

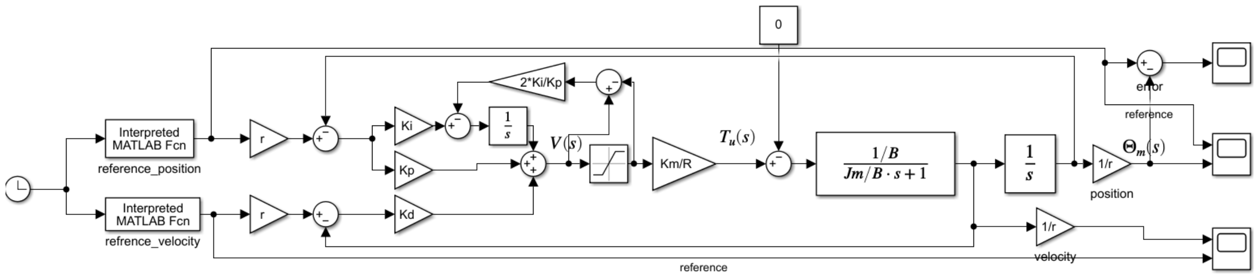

Figure 23 PID Model

6.1 Without disturbance

Tuning PID by the choice of one triple pole -α.

$\alpha = 17,\quad Kp = 3.4515,\quad Kd = 0.0951,\quad Ki = 19.5584$

$\alpha = 18,\quad Kp = 3.8695,\quad Kd = 0.1071,\quad Ki = 23.2169$

$\alpha = 19,\quad Kp = 4.3114,\quad Kd = 0.1190,\quad Ki = 27.3054$

$\alpha = 20,\quad Kp = 4.7771\quad Kd = 0.1310,\quad Ki = 31.8476$

6.1.1 Maximal control error

6.1.1.1 For cubic trajectory

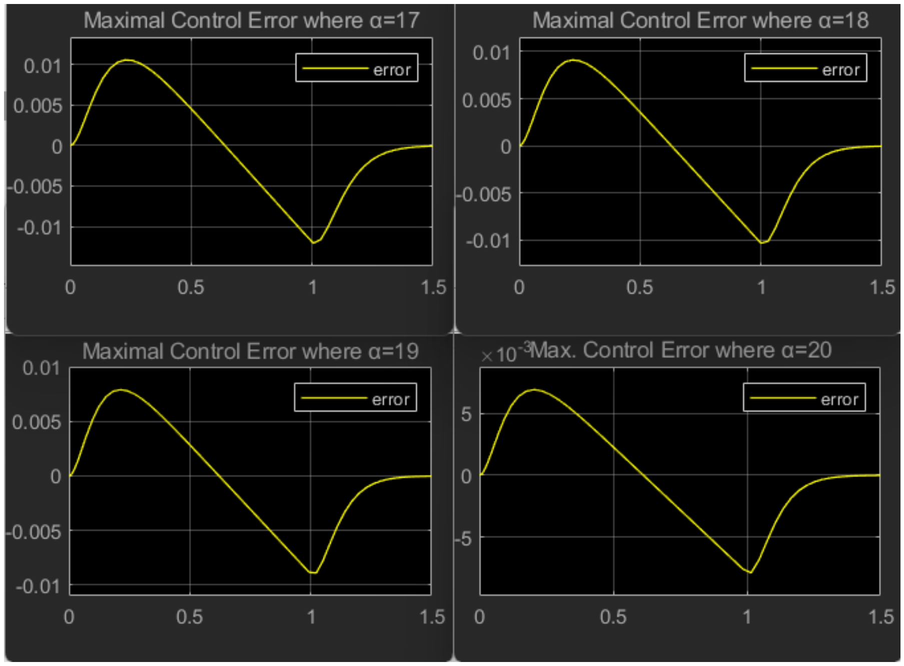

Figure 24 Control error for PID model with cubic reference trajectory without disturbance

6.1.1.2 For LSPB trajectory

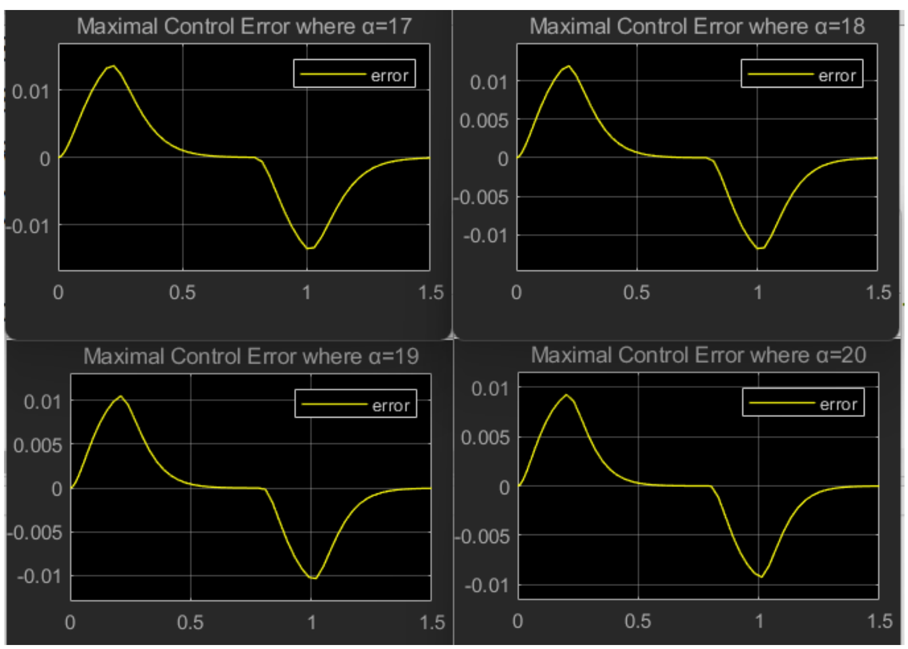

Figure 25 Control error for PID model with LSPB reference trajectory without disturbance

From the error plots it can be seen that α=20 satisfies the maximal control error for both the LSPB and cubic trajectory cases. So α=20 will be used.

6.1.2 Arm position

Using α=20 the Arm Position for PID model with cubic and LSPB reference trajectory without disturbance is shown as follow

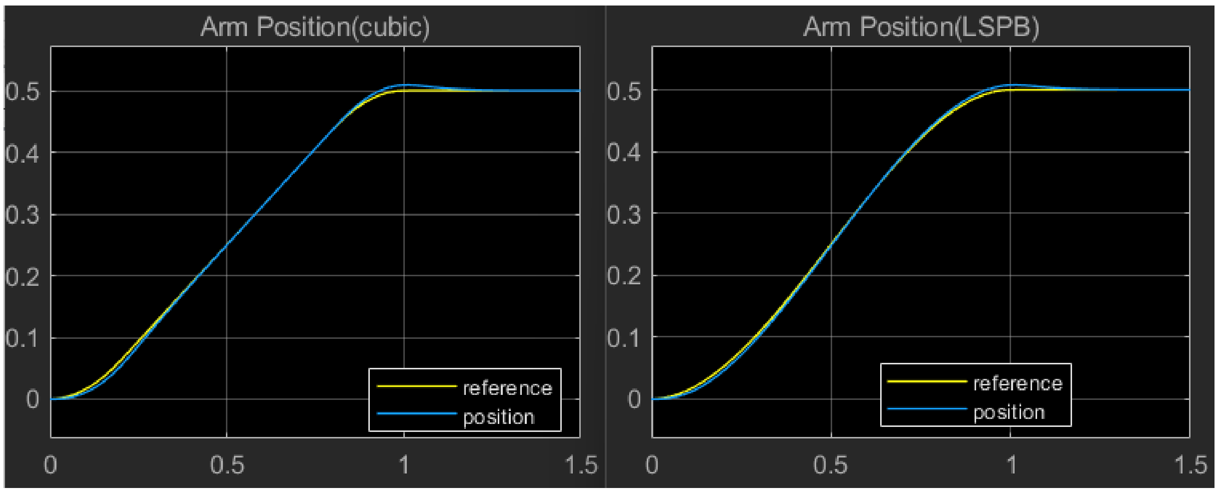

Figure 26 Arm Position for PID model with cubic and LSPB reference trajectory without disturbance

6.1.3 Arm velocity

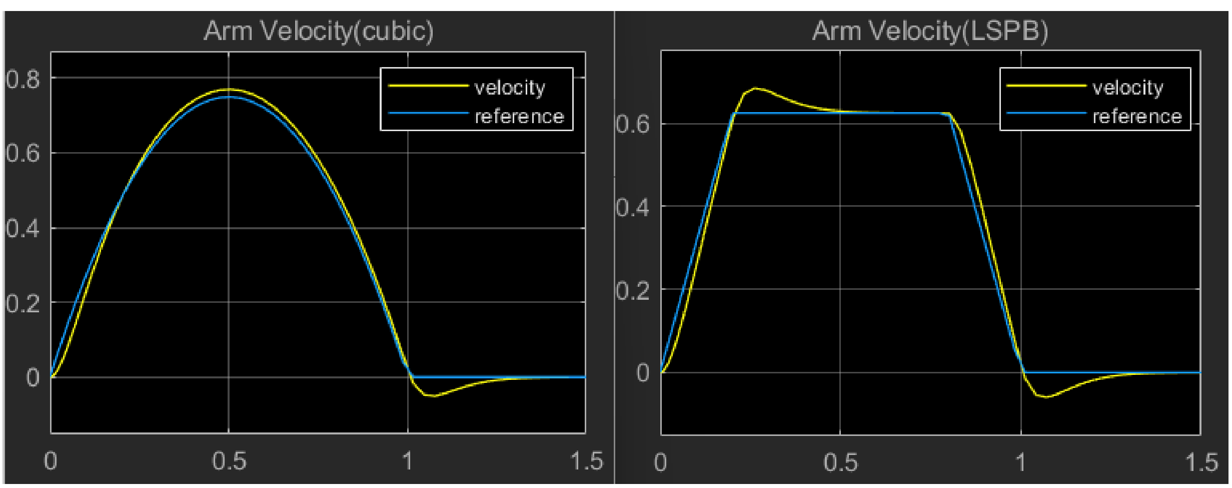

Figure 27 Arm Velocity for PID model with cubic and LSPB reference trajectory without disturbance

6.2 With disturbance

6.2.1 Maximal control error

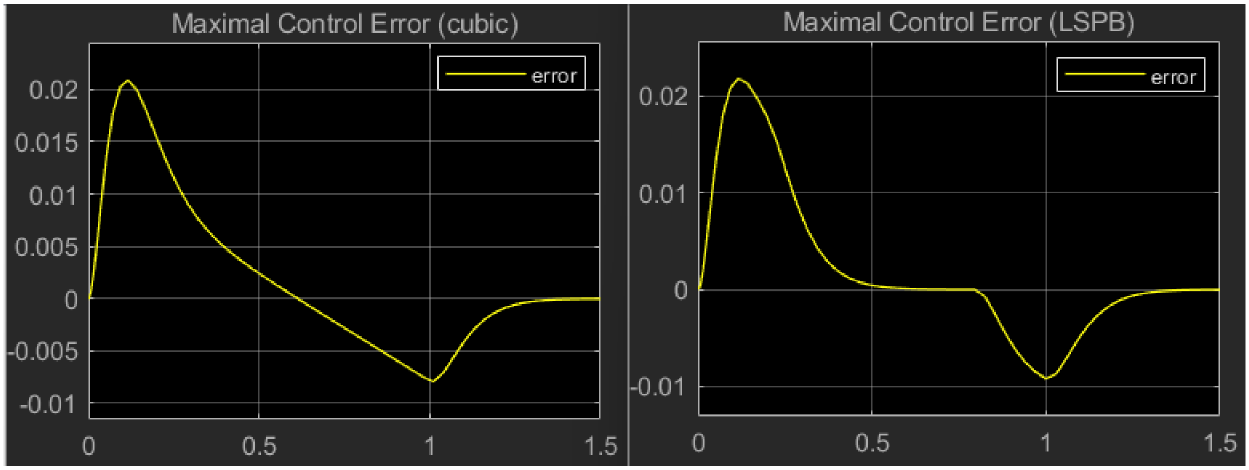

Figure 28 Control error for PID model with cubic and LSPB reference trajectory with disturbance

After seeing the error plots with the disturbance value. It is seen that now the error has passed the Maximal control error of 0.01. Since we don't have steady state disturbance here after control. Thus the control can be done.

6.2.2 Arm position

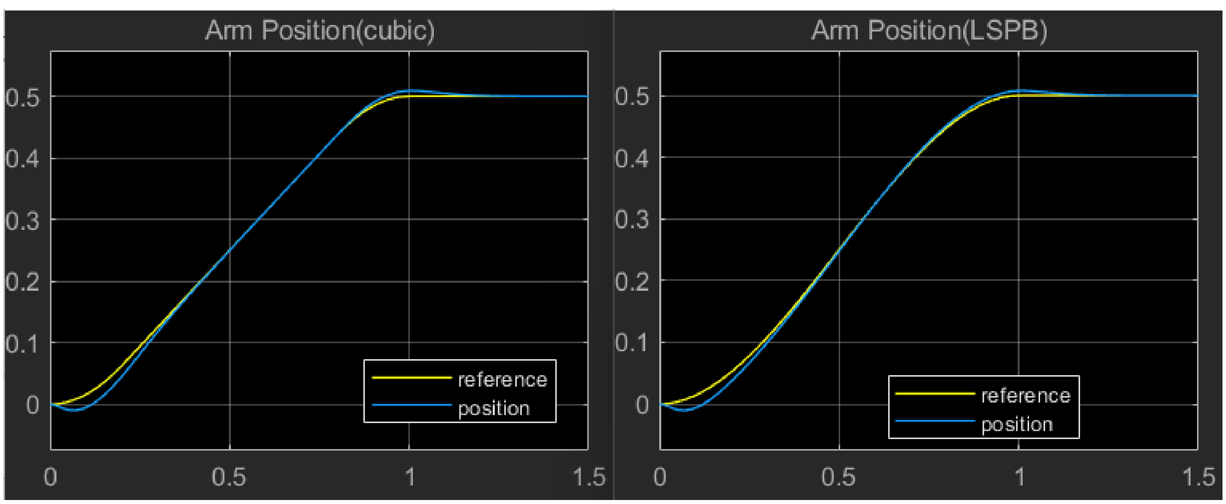

Figure 29 Arm Position for PID model with cubic and LSPB reference trajectory without disturbance

6.2.3 Arm velocity

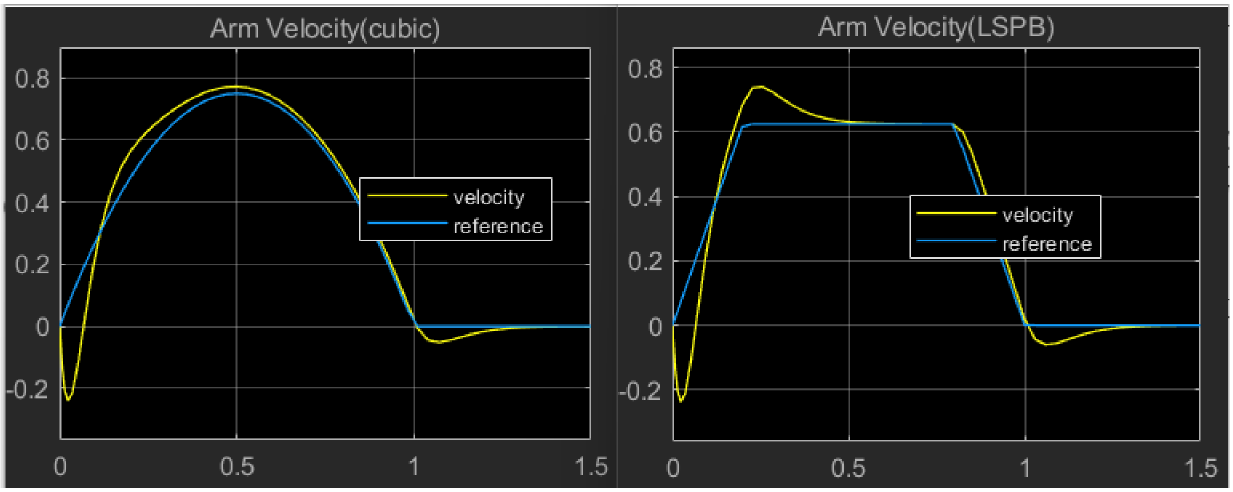

Figure 30 Arm Velocity for PID model with cubic and LSPB reference trajectory with disturbance

6.3 Behavior of the PID control system for the step change

6.3.1 Without anti-windup

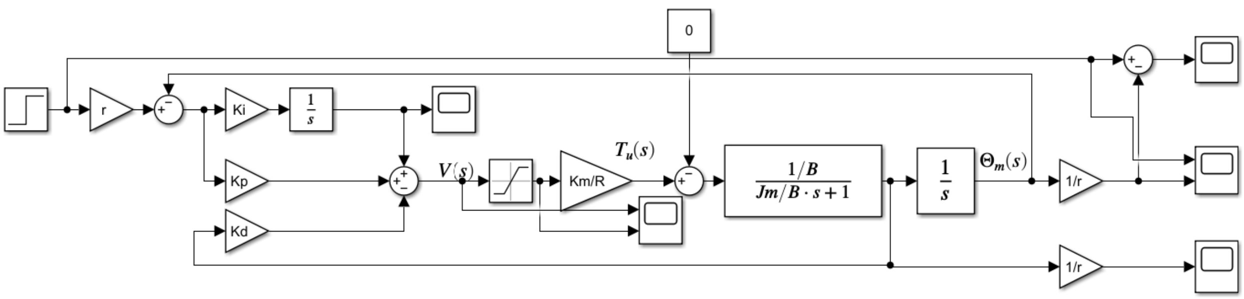

Figure 31 Modified PI-D without anti-windup model

6.3.2 With anti-windup

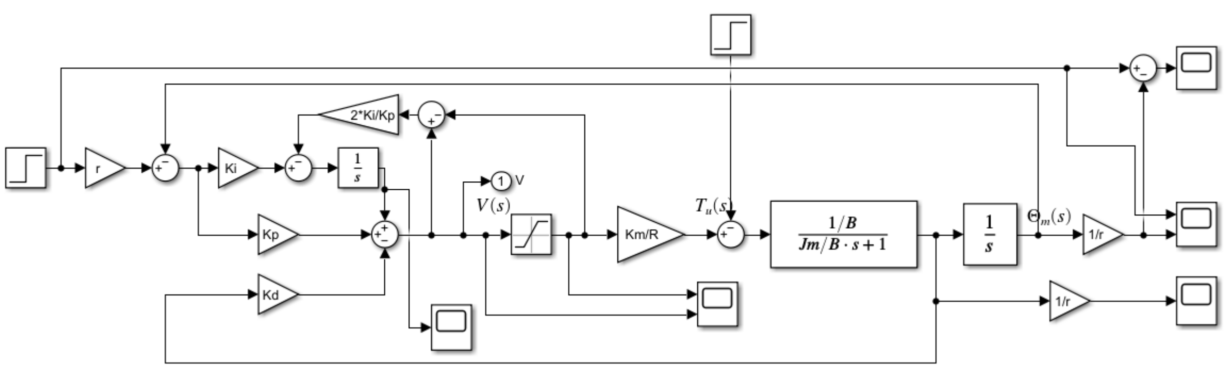

Figure 32 Modified PI-D with anti-windup model

6.3.2.1 Maximal control error

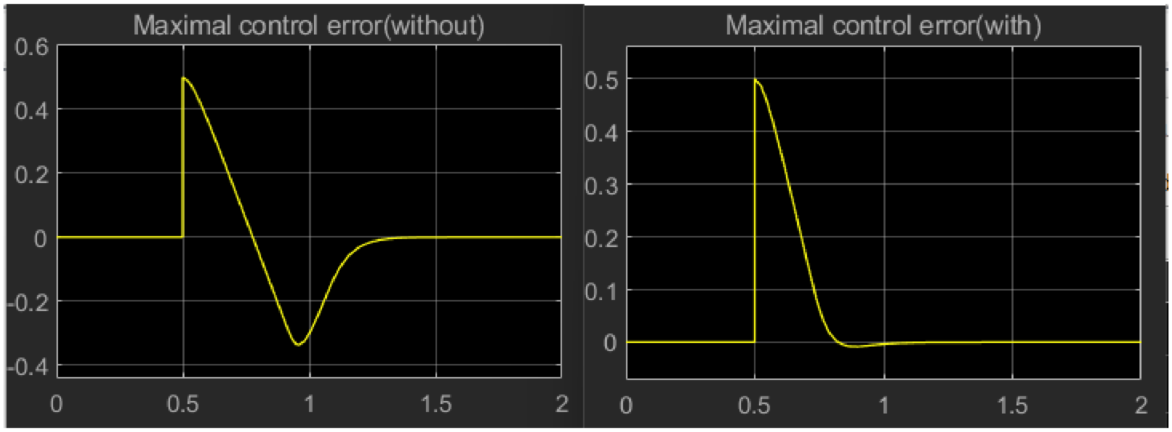

Figure 33 Control error for Modified PID model with step-change with and without anti-windup

6.3.2.2 Arm position

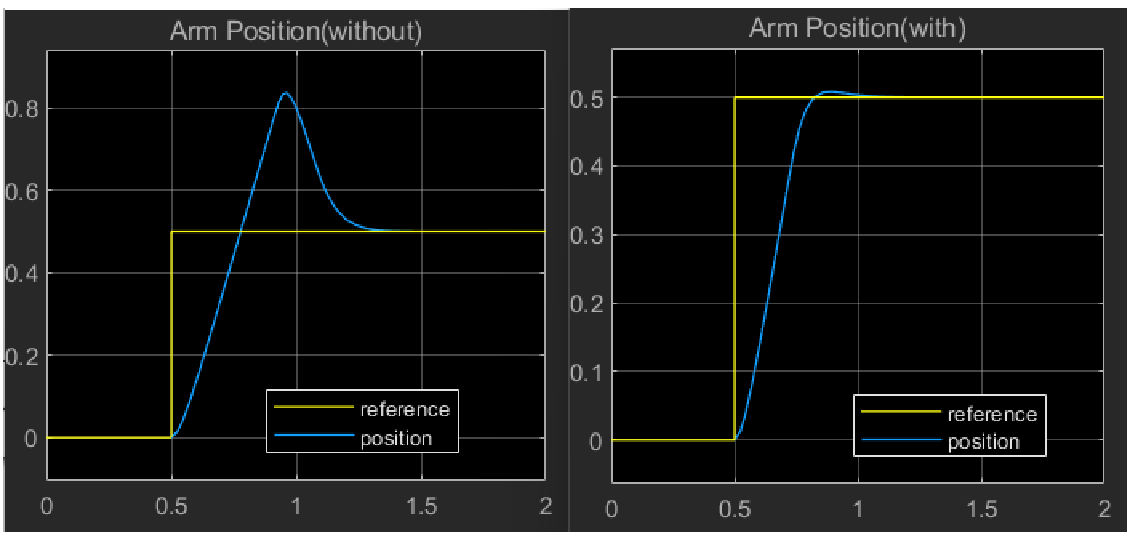

Figure 34 Arm position for Modified PID model with step-change with and without anti-windup

6.3.2.3 Arm velocity

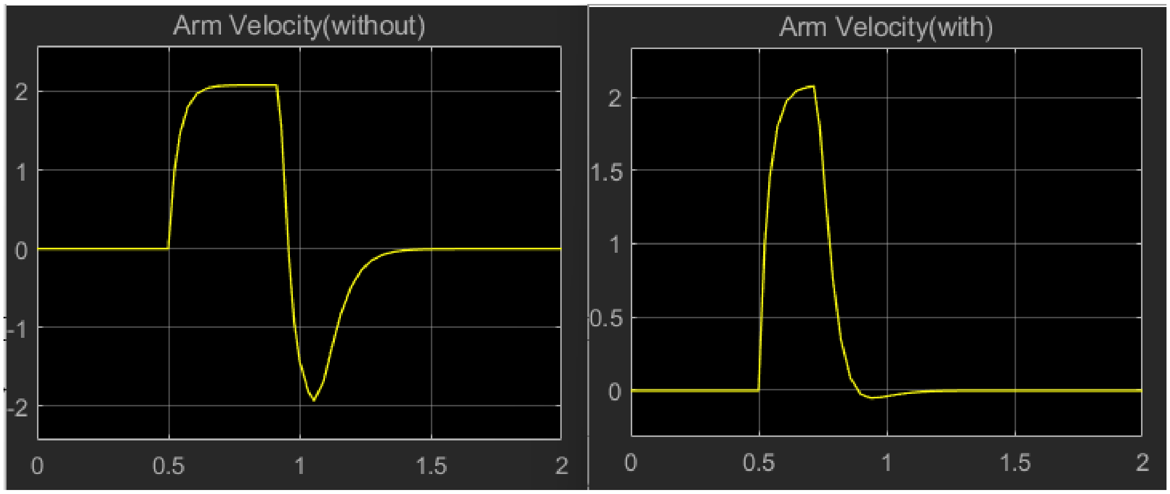

Figure 35 Arm velocity for Modified PID model with step-change with and without anti-windup

6.3.2.4 Integrator output

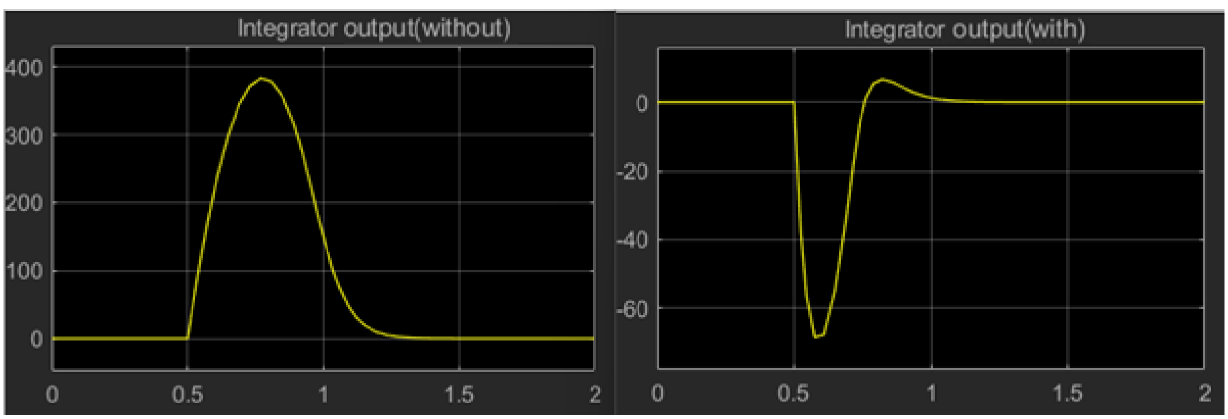

Figure 36 Integrator output for Modified PID model with step-change with and without anti-windup

6.3.2.5 PID output and Manipulator input

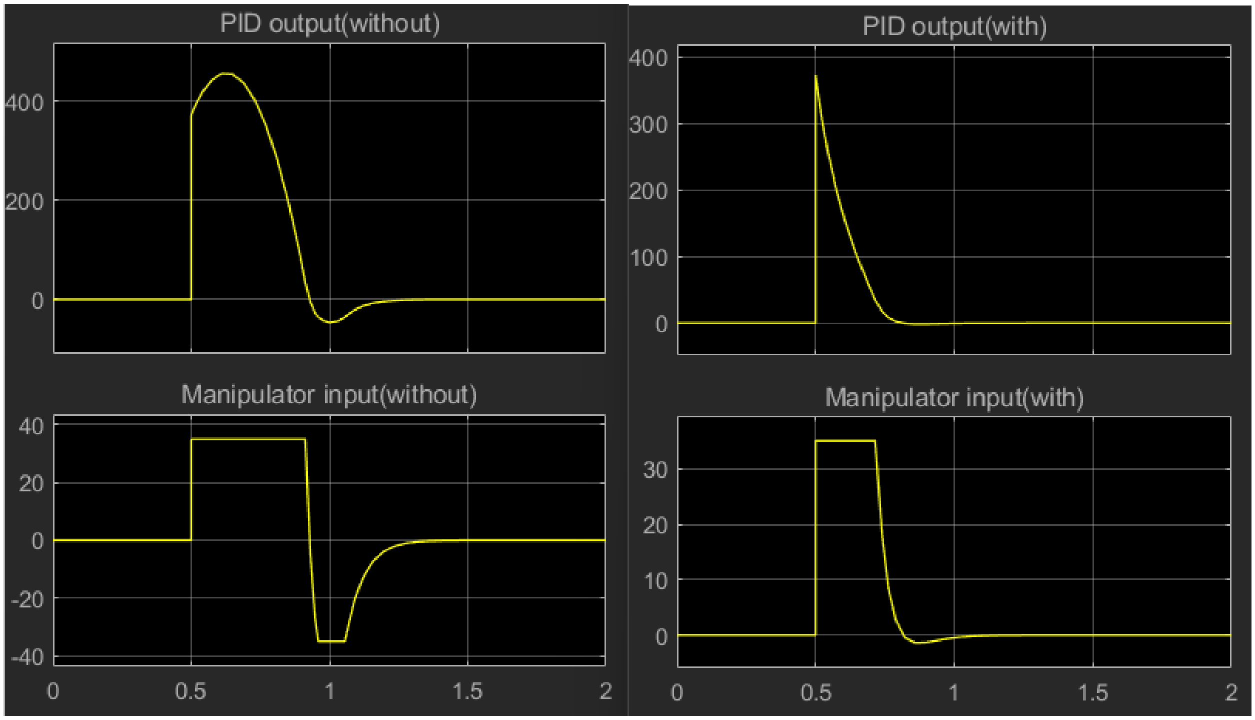

Figure 37 PID output and Manipulator input output for Modified PID model with step-change with and without anti-windup

Thus it is seen that

7 Feedback-Feedforward Control for sinusoidal arm reference trajectory

7.1 With Feedforward

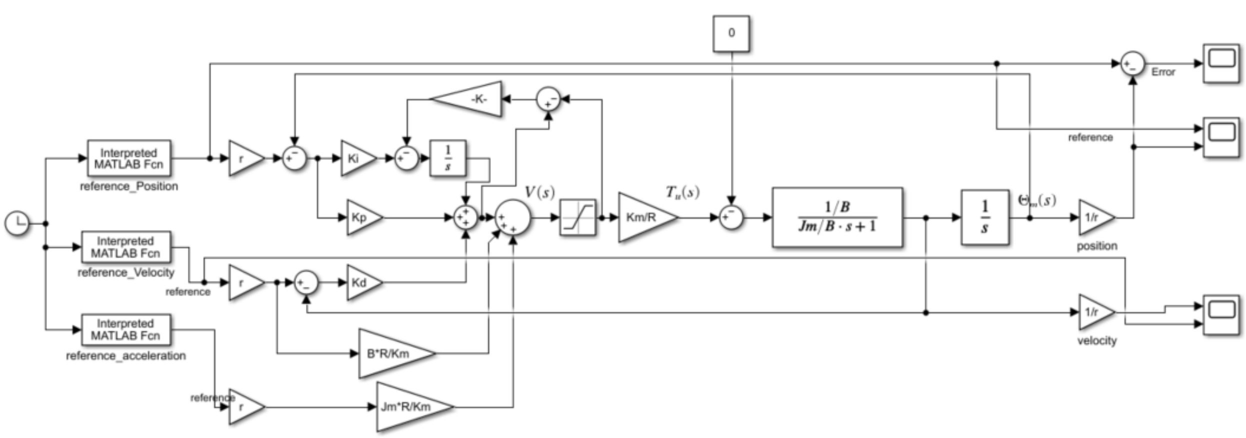

Figure 38 PID with feed forward model with sinusoidal reference trajectory

7.2 Without Feedforward

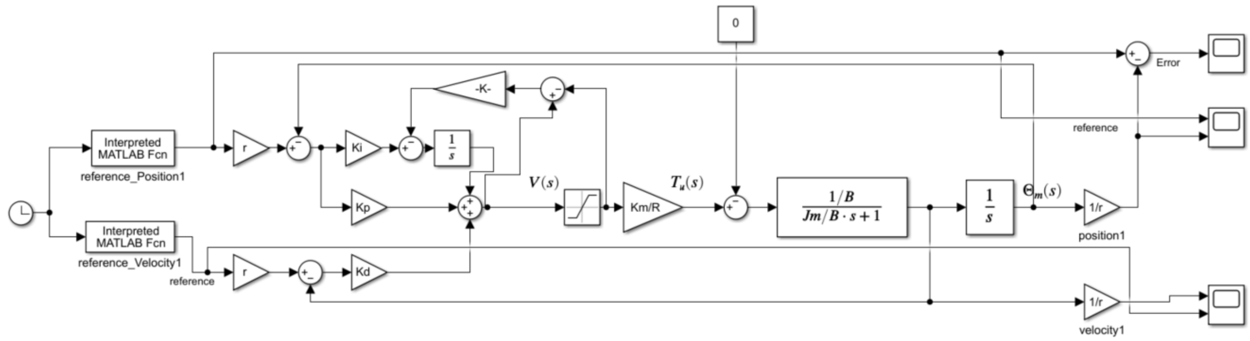

Figure 39 PID without feed forward model with sinusoidal reference trajectory

7.2.1 Comparisons

7.2.1.1 Maximal control error

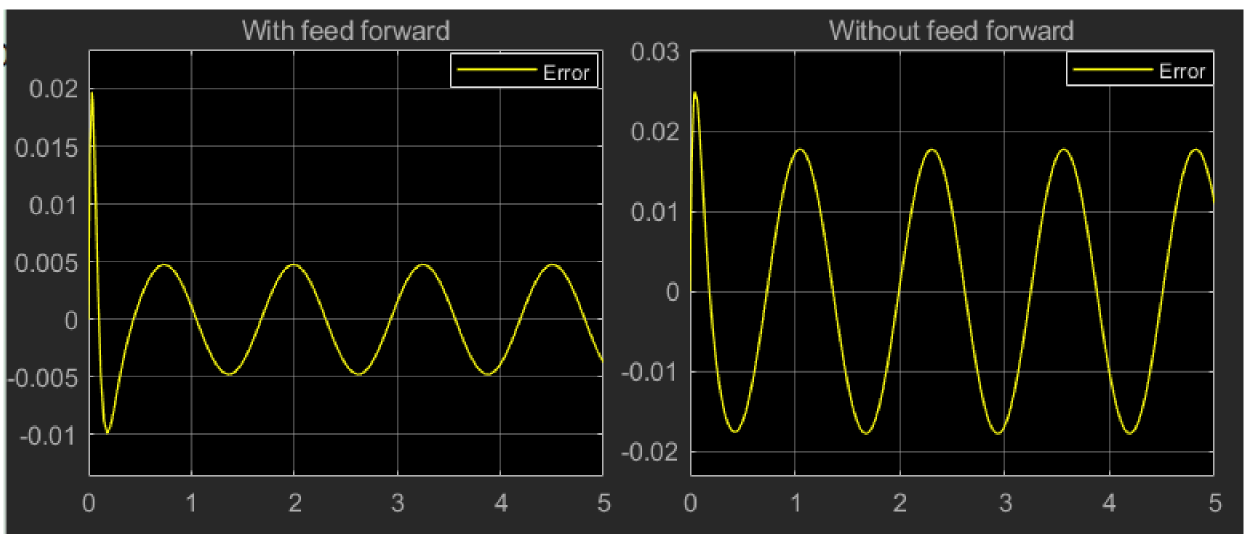

Figure 40 Control error with and without feed-forward

7.2.1.2 Arm Position

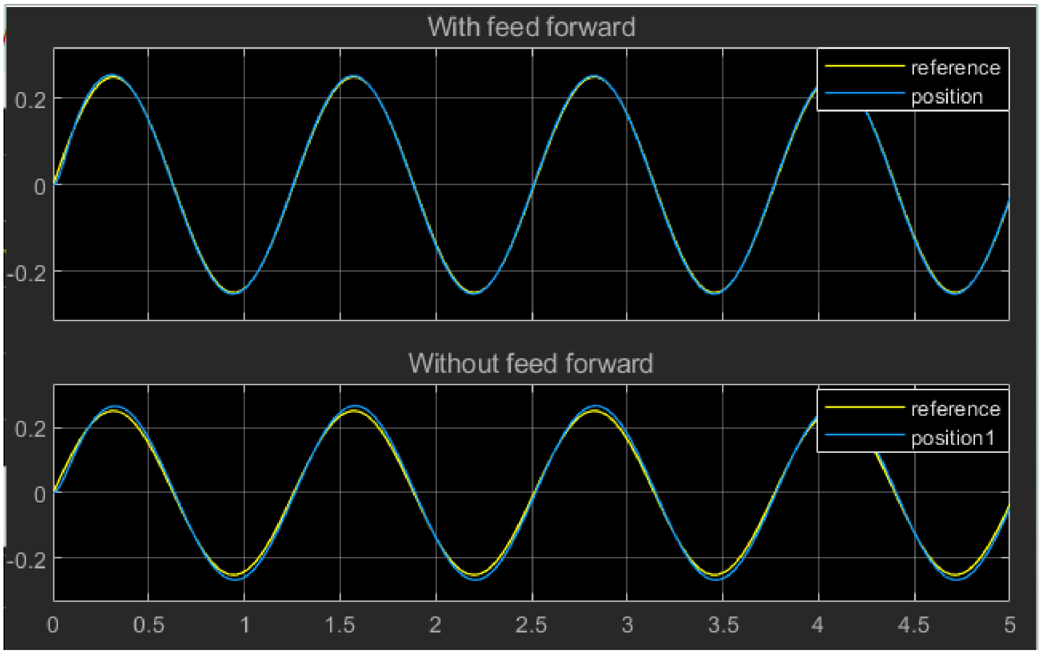

Figure 41Arm Position with and without feed-forward

7.2.1.3 Arm Velocity

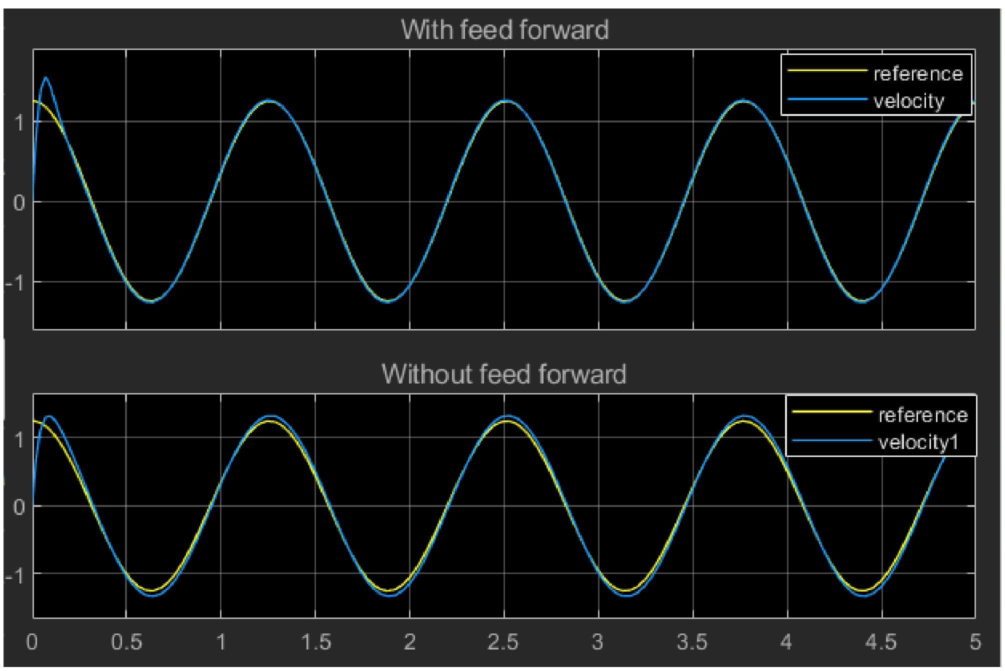

Figure 42 Arm Velocity with and without feed-forward

8 Conclusion

In this homework single link manipulator is designed. Beginning by modelling accurate and simplified model followed by modeling of PD and PID control system. During the design several cases are compared.