

Institute of Automation and Robotics

Homework 2

in the subject of Modelling and control of manipulator

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submitted to

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# Given Data – homework 2 (no. 11)

Jm = 5.5e–4 kg.m2;

Kb = 0.105 V/(rad/s);

Km = 0.105 N.m/A;

L = 0.9 e-3 H;

R = 0.76 Ω;

Bm = 4e–4 N.m/(rad/s);

gear ratio r=156;

under saturation limits of the manipulator input signal: Vmin = –35 V, Vmax = 35 V.

τl/r = 2 N.m

ωref =α /4 [rad/s]

maximal control error between 0.01 and 0.005

tb = 0.2tm

trajectory from θ0 = 0 to θf = 0.5

The trajectory equation used are shown as follows

## Cubic trajectory equation

## LSPB trajectory equation

# Model of a single–link manipulator

Diagram, schematic

Description automatically generated

Figure Accurate Model

# Simplified model neglecting the electrical time constant

Diagram

Description automatically generated

Figure Simplified Model

## Comparison and difference plotting

### Comparisons plotting

Diagram

Description automatically generated with medium confidence

Figure Accurate vs Simplified Model

### Difference plotting

Chart

Description automatically generated

Figure Accurate vs Simplified Model(Difference)

# PD control system model for cubic reference trajectory

Diagram, schematic

Description automatically generated

Figure PD Model

Tuning PID by the choice of ω

, ,

, ,

, ,

Graphical user interface

Description automatically generated

Figure PD Control error for PD model with cubic reference trajectory

Graphical user interface

Description automatically generated with low confidence

Figure PD Arm position for PD model with cubic reference trajectory

Graphical user interface

Description automatically generated

Figure PD Arm velocity for PD model with cubic reference trajectory

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

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

Diagram, schematic

Description automatically generated

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

#### Position Error and Arm position

Graphical user interface, diagram

Description automatically generated

Figure Modified P-D Model Position Error and Arm Position

#### PD output and Manipulator input

Graphical user interface, chart

Description automatically generated

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

#### Arm velocity

Chart

Description automatically generated

Figure Modified P-D Model Arm Velocity

# PD control system model for LSPB reference trajectory

#### Position Error

Chart, line chart

Description automatically generated

Figure PD Control error for PD model with LSBP reference trajectory

#### Arm position

Chart

Description automatically generated

Figure Arm Position for PD model with LSBP reference trajectory

#### Arm velocity

Chart, line chart

Description automatically generated

Figure Arm Velocity for PD model with LSBP reference trajectory

# Influence of the constant load disturbance

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

Diagram

Description automatically generated

Figure PD Model with load disturbance of 2Nm

## For cubic reference trajectories

Chart

Description automatically generated with medium confidence

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

Chart

Description automatically generated

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

A picture containing diagram

Description automatically generated

Figure 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.

## For LSPB reference trajectories

Chart

Description automatically generated

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

Chart

Description automatically generated

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

Chart

Description automatically generated

Figure 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.

# Design of PID control system

Diagram

Description automatically generated

Figure PID Model

## Without disturbance

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

, , ,

, , ,

, , ,

, ,

### Maximal control error

#### For cubic trajectory

Graphical user interface

Description automatically generated

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

#### For LSPB trajectory

Graphical user interface, chart

Description automatically generated

Figure 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.

### Arm position

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

Graphical user interface, chart

Description automatically generated

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

### Arm velocity

Graphical user interface, chart

Description automatically generated

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

## With disturbance

### Maximal control error

Chart

Description automatically generated

Figure 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.

### Arm position

Graphical user interface

Description automatically generated

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

### Arm velocity

Graphical user interface, chart, line chart

Description automatically generated

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

## Behavior of the PID control system for the step change

### Without anti-windup

Diagram, schematic

Description automatically generated

Figure Modified PI-D without anti-windup model

### With anti-windup

Diagram, schematic

Description automatically generated

Figure Modified PI-D with anti-windup model

#### Maximal control error

Chart

Description automatically generated

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

#### Arm position

Chart

Description automatically generated

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

#### Arm velocity

Graphical user interface, chart

Description automatically generated

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

#### Integrator output

Graphical user interface

Description automatically generated

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

#### PID output and Manipulator input

Graphical user interface, chart

Description automatically generated

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

Thus it is seen that

# Feedback-Feedforward Control for sinusoidal arm reference trajectory

## With Feedforward

Diagram, schematic

Description automatically generated

Figure PID with feed forward model with sinusoidal reference trajectory

## Without Feedforward

Diagram

Description automatically generated

Figure PID without feed forward model with sinusoidal reference trajectory

### Comparisons

#### Maximal control error

Chart

Description automatically generated

Figure Control error with and without feed-forward

#### Arm Position

Chart

Description automatically generated

Figure Arm Position with and without feed-forward

#### Arm Velocity

Chart

Description automatically generated

Figure Arm Velocity with and without feed-forward

# 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.