Practical Exercise Project Assignment (2)

(AE4313 + AE4313P)

Nonlinear Spacecraft Attitude Control System Design

(3+1 ECTS)

Date: March 9, 2016

Introduction

This is the project assignment for the course on Spacecraft Attitude Dynamics and Control (AE4313) and the associated practicum (AE4313P). Students who wish to finish these courses will have to complete this project. 3+1 ECTS in total will be issued to those who are able to finish the exercise successfully.

Spacecraft attitude control is basically a nonlinear control problem when large attitude manoeuvres are commanded. Most attitude controller designs are so far still based on linear control concept (PDs or PIDs). An effective approach of treating nonlinear control problems has been learned in the course. The approach is called Nonlinear Dynamic Inversion (NDI) or Feed-Back Linearization (FBL). This assignment concerns an application of this innovative control approach to a nonlinear spacecraft attitude control problem. NDI or FBL in the inner control loop will have to be designed for linearizing the nonlinear system exactly and the complete control system will have to be designed by combining an outer loop linear PD or PID controller. Both Euler angles and quaternions are required for system models and controller designs.

There are three approaches to design the spacecraft nonlinear attitude control system using NDI/FBL control concept:

1. Model based approach,
2. Model based approach with time scale separation principle,
3. Sensor based incremental approach with time scale separation principle.

Students are asked to apply all these three approaches to design the attitude control system.

The project has to be done individually.

The report and the associated Matlab code in a separate file should be submitted not later than Friday, the 15th of April, 2016. Later submission needs to be applied for a special permission from the course instructor.

Spacecraft Specifications:

Spacecraft orientation:	Nadir pointing
Spacecraft orbit:	Circular, 700 km orbit height
Attitude control type:	active three-axis control with ideal control actuators (no limit for the control torque)
Satellite inertia property:	$\begin{bmatrix} 124.531 & 0 & 0 \\ 0 & 124.586 & 0 \\ 0 & 0 & 0.704 \end{bmatrix} kgm^2$
Disturbance torques:	$T_d = \begin{bmatrix} 0.0001 & 0.0001 & 0.0001 \end{bmatrix}^T \; Nm$
Available attitude measurements:	all roll, pitch, yaw angles and all quaternions
Angular velocity measurements:	three angular velocity components
Attitude angle measurement errors:	0
Angular velocity measurement errors:	0
Sample time:	0.1 s
Simulation duration:	1500 s
Initial attitude:	30 degrees
Reference commands:	0 s – 99.9 s 0 degrees (all axes) 100 s – 500 s 70 degrees (all axes) 500.1 s – 900 s -70 degrees (all axes) 900.1 s – 1500 s 0 degrees (all axes)

Assignments:

1. Develop the complete spacecraft dynamics and kinematics equations for the three-axis-stabilised satellite (Euler angles, quaternions) and implement these simulation models using Matlab;

2. Design linear controllers (PD) for both Euler angle and quaternion models;

3. Introduce attitude manoeuvres as required (reference commands);

4. Simulate the performance of these controlled systems (Euler angles and quaternions);

5. Design the attitude control system using the above mentioned three approaches;

6. Simulate the performance of these spacecraft attitude control systems for both Euler angle and quaternion models;

7. Present the algorithms and results in the report.

8. For NDI attitude control system design in terms of quaternions, control variable should be selected as error quaternions which are calculated with

$$\begin{bmatrix} q_{1e} \\ q_{2e} \\ q_{3e} \\ q_{4e} \end{bmatrix} = \begin{bmatrix} q_{4c} & q_{3c} & -q_{2c} & -q_{1c} \\ -q_{3c} & q_{4c} & q_{1c} & -q_{2c} \\ q_{2c} & -q_{1c} & q_{4c} & -q_{3c} \\ q_{1c} & q_{2c} & q_{3c} & q_{4c} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix}$$

where q_{ie}, q_{ic}, q_i are error, commanded and actual quaternions. Only first three error quaternions are selected as control variables.