Nonlinear control and aerospace applications - Lab session 4

The dynamics of a spacecraft (called the chaser) in a neighborhood of another spacecraft (called the target), traveling in a circular orbit is described by the Hill-Clohessy-Wiltshire equations:

$$\begin{aligned}\ddot{z}_1 &= 3\omega^2 z_1 + 2\omega \dot{z}_2 + u_1 \\ \ddot{z}_2 &= -2\omega \dot{z}_1 + u_2 \\ \ddot{z}_3 &= -\omega^2 z_3 + u_3\end{aligned}$$

where z_i are the chaser coordinates relative to the target in a suitable frame of reference, $\omega = 0.0011$ rad/s, and

- state: $x = (x_1, x_2, x_3, x_4, x_5, x_6) = (z_1, z_2, z_3, \dot{z}_1, \dot{z}_2, \dot{z}_3)$
- input: $u = (u_1, u_2, u_3)$.

All quantities are (and will be) expressed in SI units.
Before preceding, download the NMPC Matlab library from the course web site.

Exercise 1

1. Design a NMPC controller, able to drive the chaser to the state target point

$$r = (20, 0, 0, 0, 0, 0).$$

   The following design parameters can be chosen:

   - $T_s \in [1, 5]\, s$, $T_p \in [50, 120]\,$s;
   - weight matrices: $Q = 0.1I$, $P = 10I$, $R = I$;

   In this first exercise, assume that no constraints are necessary.

2. Test the controller in simulation on Simulink, letting the chaser spacecraft starting from reasonable random initial conditions (positions of the order of hundreds of meters, velocities null or small).

Exercise 2
Repeat Exercise 1, imposing the following constraints:

- $X_c = \{x : \|(x_1, x_2, x_3)\| > 10\} \leftarrow$ safety sphere around the target spacecraft
- $U_c = \{u : \|u\|_\infty \leq 1\} \leftarrow$ thruster saturation.

Exercise 3
Repeat Exercise 2, changing the values of the design parameter (and the constraints), in order to study which are the resulting effects on the control performance. In particular, the trade-off between control performance and command effort should be analyzed.

Exercise 4
Suppose that we would like to tackle the control problem of Exercise 2 using not NMPC but other methods, such as gain scheduling, feedback linearization, sliding mode control, or a purely linear technique.

- Which would be the drawbacks (and advantages) of these methods, compared to NMPC?
- How would it be possible to satisfy the constraints using these methods?