OptReg lab report

Group ??
Vemund Rogne
Jørgen Haaland

February 25, 2021

NTNU
Department of Engineering Cybernetics

Contents

1 10.2 - Optimal Control of Pitch/Travel without Feedback

1.1 Derivation of a continous time state space model

In this part of the exercise we will disregard elevation, therefore we assume $e = 0$ and do include it in the model.

The state-vector, $\boldsymbol{x}$ is defined as:

$$\boldsymbol{x} = \begin{bmatrix} \lambda & r & p & \dot{p} \end{bmatrix}^T, \tag{1}$$

where λ is travel, r is speed of travel (travelrate), p is pitch and $\dot{p}$ is pitchrate.

The dynamic equations for the system was given in the problem description. The following equations were given:

$$\dot{\lambda} = r \tag{2a}$$

$$\dot{r} = -K_2 p, \quad K_2 = \frac{K_p l_a}{J_t} \tag{2b}$$

$$\dot{p} = \dot{p} \tag{2c}$$

$$\ddot{p} = -K_1 K_{pd} \dot{p} - K_1 K_{pp} p + K_1 K_{pp} pc, \quad K_1 = \frac{K_f l_h}{J_p} \tag{2d}$$

The state-space form of the system therefore becomes:

$$\underbrace{\begin{bmatrix} \dot{\lambda} \\ \dot{r} \\ \dot{p} \\ \ddot{p} \end{bmatrix}}_{\dot{\boldsymbol{x}}} = \underbrace{\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -K_2 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -K_1 K_{pp} & -K_1 K_{pd} \end{bmatrix}}_{\boldsymbol{A}_c} \begin{bmatrix} \lambda \\ r \\ p \\ \dot{p} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 0 \\ 0 \\ K_1 K_{pp} \end{bmatrix}}_{\boldsymbol{B}_c} \underbrace{p_c}_{u} \tag{3}$$

1.1.1 Stability and eigenvalues

The properties of this system is dependent on physical constants $(l_a, J_t, ...)$ and control parameters (K_{pp}, K_{pd}).

Symbolic expressions in Matlab shows that the eigenvalues of A are:

$$\lambda = \pm \frac{1}{2} \left(\sqrt{-K_1(-K_1 K_{pd}^2 + 4K_{pp})} - K_1 K_{pd} \right) \tag{4}$$

The eigenvalues of the continous model, with $K_{pp} = 0, 1, K_{pd} = 0, 4$ are:

$$\begin{bmatrix} 0 \\ 0 \\ -0.26 + 0.24i \\ -0.26 - 0.24 \end{bmatrix} \tag{5}$$

1.2 Discretizing the continout time model

A discretized model is required for generating an optimal trajectory. *[...] continous time models require quite different solution methods* [1]

1.2.1 Discretizing model

Forward Euler method is given by:

$$\boldsymbol{x}[k+1] = \boldsymbol{I}\boldsymbol{x}[k] + T\boldsymbol{A_c}\boldsymbol{x}[k] + T\boldsymbol{B}_c \tag{6}$$

, where T is the timestep

timestep in the discretization??

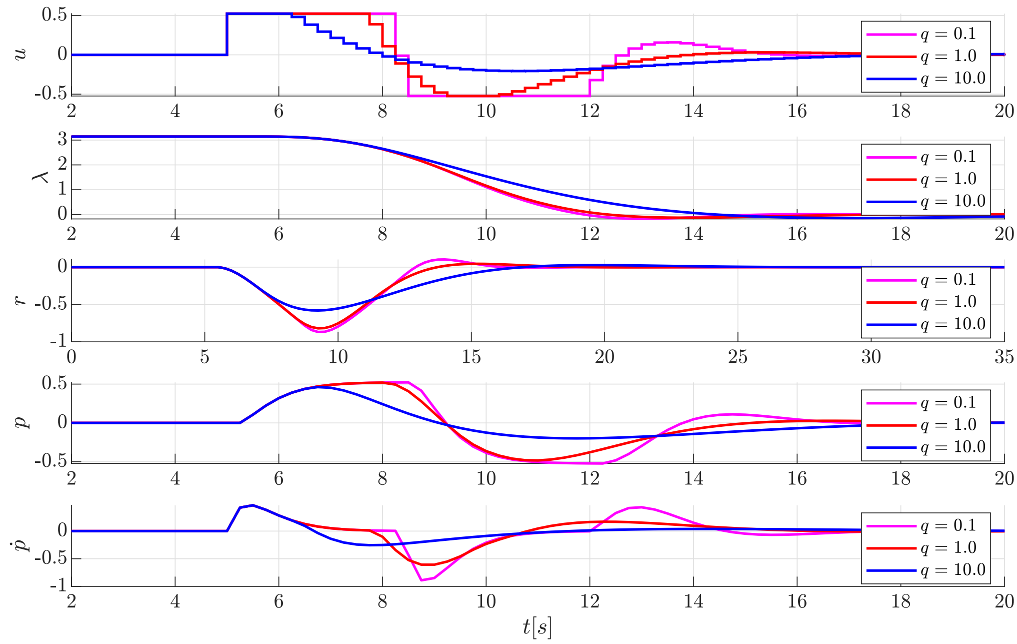


Figure 1: Manipulated variable and outputs with different values of q.

Add reference to linsys slides

. Reformulating this, we can write:

$$\boldsymbol{x}_{k+1} = \underbrace{(\boldsymbol{I} + T\boldsymbol{A}_c)}_{\boldsymbol{A}} \boldsymbol{x}_k + \underbrace{T\boldsymbol{B}_c}_{\boldsymbol{B}} u_k \tag{7}$$

1.2.2 Checking stability

The stability condition for eq. (7) is:

$$|1 + T\lambda| \leq 1 \tag{8}$$

, where λ is an eigenvalue of $\boldsymbol{A}_c$ in eq. (7).

Where is this equation from? I believe that it works, but we should either derive it or reference where we found it. ANSWER: From linsys slides, see above

Using MATLAB we found the eigenvalues of $\boldsymbol{A}$ to be ...

Add Matlab appendix

find eigenvalues

1.3 The open loop optimization problem

How is it formulated?

1.4 The weights of the optimization problem

Try using the values 0.1, 1 and 10 as weights q. Plot the manipulated variable and the output. Comment the results with respect to the different weights chosen.

1.5 The objective function

Furthermore, discuss the objective function (15) (in the lab assignment text) in particular the term $(\lambda_i - \lambda_f)^2$. *For instance, could any unwanted effects arise from steering the helicopter to* $\lambda = \lambda_f$ *with this objective function?*

1.6 Experimental results

Printouts of data from relevant experiments (plots). Discussion and analysis of the results. Answer 10.2.2.7 here.

1.7 MATLAB and Simulink

Code and diagrams go here

2 10.3 - Optimal Control of Pitch/Travel with Feedback (LQ)

2.1 LQ controller

Briefly explain LQ controller. Especially, but not limited to, what is the role of the matrices Q and R? Justify your choice of weights.

2.2 Model Predictive Control

Answer 10.3.1.3 here.

2.3 Experimental results

Printouts of data from relevant experiments (plots). Discussion and analysis of the results. Answer 10.3.2.5 here.

2.4 MATLAB and Simulink

Code and diagrams go here

3 10.4 - Optimal Control of Pitch/Travel and Elevation with Feedback

3.1 The continuous model

Answer 10.4.1.1

3.2 The discretized model

Answer 10.4.1.2

3.3 Experimental results

Printouts of data from relevant experiments (plots). Discussion and analysis of the results. Answer 10.4.2.6 here.

3.4 Decoupled model

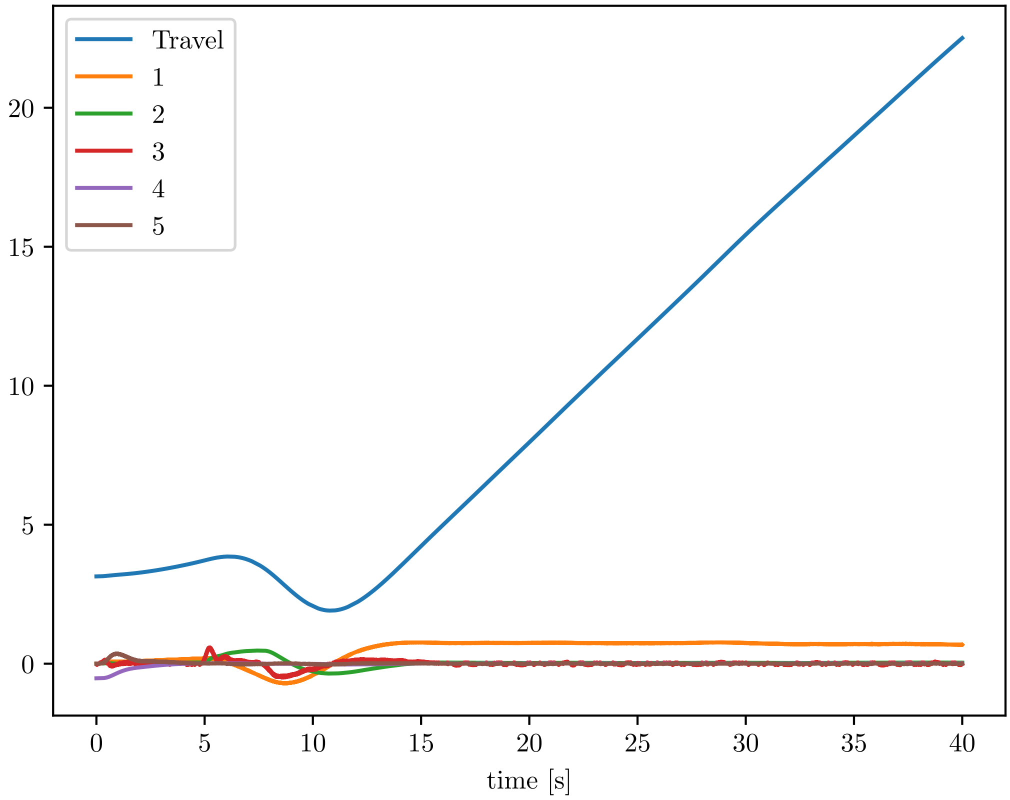
Answer 10.4.2.7

3.5 MATLAB and Simulink

Code and diagrams go here

3.6 Optional exercise

Which constraints did you add? What was the results? Plots? Discussion?



References

[1] Bjarne Foss and Tor Aksel N. Heirung. *Merging optimization and control*. 2016.