Estimation and Learning in Aerospace 2022/2023 exam project

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Project tasks

The project deals with the dynamics of a multirotor UAV and involves the following two tasks.

Task I

- System identification of longitudinal dynamics from simulated data for a given input

Task II

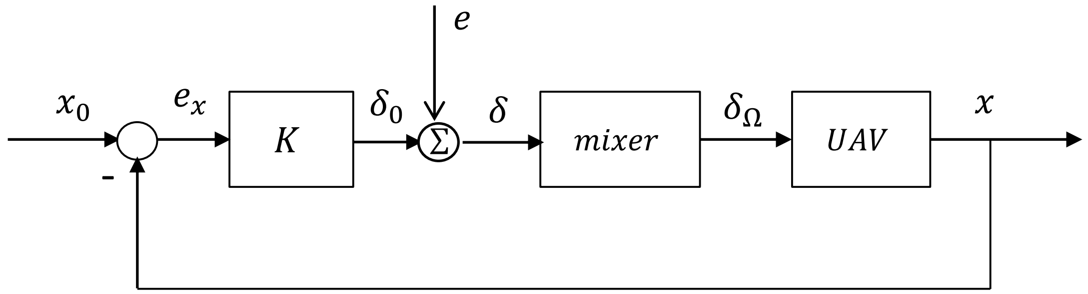
- Optimisation of experiment design to maximise model accuracy

A small quadrotor

Weight: 270g
Dimensions: 20 x 20 x 4 cm
Diameter (motor-to-motor distance): 16cm
Hovering time: 7’30’’

ANT-X

Identification experiments and I/O estimation data



Decoupled dynamics

- *Longitudinal dynamics*
  - Input: δ_{lon}/ Outputs: $q,\ a_x$
  - Known time delay of 4 sampling intervals.

Linearised model for longitudinal dynamics

State equation

$$\begin{bmatrix} \dot{u} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & X_q & -g \\ M_u & M_q & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} X_\delta \\ M_\delta \\ 0 \end{bmatrix} \delta_{lon}$$

u Longitudinal (body) velocity [m/s]
q Pitch rate [rad/s]
θ Pitch angle [rad]
a_x Longitudinal (body) acceleration [m/s^2]
δ_{lon} Pitch moment [normalised to -1, +1 range]

Output equation

$$\begin{bmatrix} q \\ a_x \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ X_u & X_q & 0 \end{bmatrix} \begin{bmatrix} u \\ q \\ \phi \end{bmatrix} + \begin{bmatrix} 0 \\ X_\delta \end{bmatrix} \delta_{lon}$$

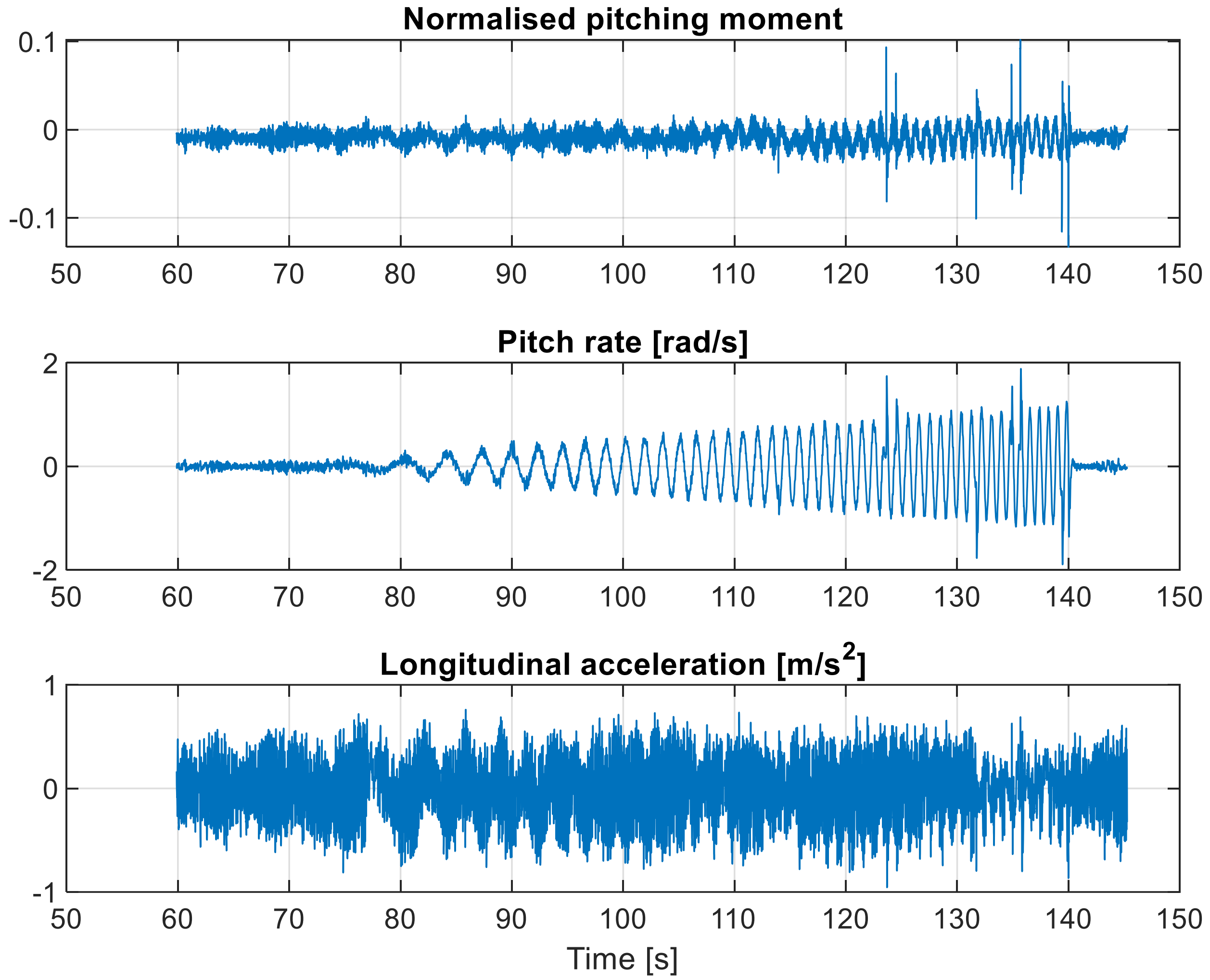
Model parameters: $\Theta = \begin{bmatrix} X_u \\ X_q \\ M_u \\ M_q \\ X_\delta \\ M_\delta \end{bmatrix}$

+ delay (computational time, sensor readings, …)

Longitudinal dynamics: excitation signal

- Experiments are carried out under position and attitude feedback, in order to guarantee safe operation.

- Baseline excitation input is a long duration sweep: excite low-frequency translational dynamics



Task 1: model identification

Use the simulator and the provided baseline excitation to:

- Identify a grey-box model for the longitudinal dynamics of the multirotor (input: total pitching moment; outputs: pitch rate and longitudinal acceleration) using the response to the sweep provided in the ExcitationM.mat file

- Assess the uncertainty of the identified model

Check if uncertainty measure through the Fisher Matrix can be computed from the Sensitivity.

Note that the open loop dynamics is *unstable*

Task 2: optimisation of experiment design

- The identified model can be used to re-design the experiment so as to optimise the accuracy of the model

- Therefore the second task of the project consists in
  - Defining and parameterising a class of inputs for the experiment (see also the attached document)
  - Defining a performance metric for model quality
  - Optimising the input class to maximise the quality of the obtainable model.
  - Evaluating the quality of the optimal obtainable model.

Initial model

An initial identified model is provided to be able to run the simulator, te parameters are given in the script main_quad_ANTX.m which runs the simulator

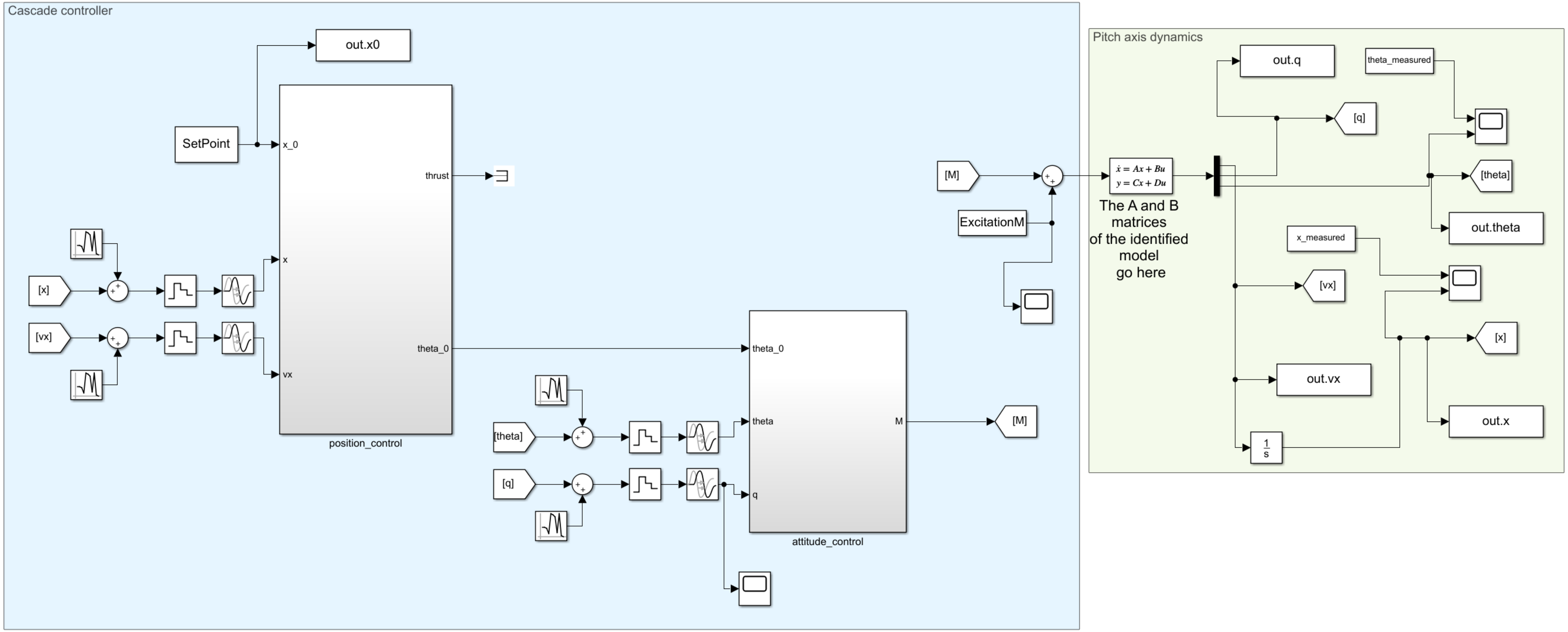
Simulator

The simulator is representative of the local linear closed-loop dynamics of the drone and combines the identified model with a complete model of the full attitude and position control system.

It includes the following files:

- main_quad_ANTX.m (which calls parameters_controller.m): set up the parameters and run the simulation
- ExcitationM.mat contains the vectors of time and normalised pitching moment corresponding to the baseline excitation
- Simulator_Single_Axis.slx the Simulink model corresponding to the closed-loop longitudinal dynamics

Simulator


Cascade controller
out.x0
SetPoint
x_0
thrust
[x]
x
[vx]
vx
theta_0
position_control
theta_0
[theta]
theta
M
[q]
q
attitude_control
[M]
[M]
ExcitationM
Pitch axis dynamics
$\dot{x} = Ax + Bu$
$y = Cx + Du$
The A and B matrices of the identified model go here
out.q
theta_measured
[q]
[theta]
out.theta
x_measured
[vx]
[x]
out.vx
out.x
$\frac{1}{s}$

Outputs

- Model identified using data generated with the provided excitation input:
    - Estimated parameters
    - Associated uncertainties
- Formulation of the experiment design problem
- Implementation of the solution
- Results:
    - Optimised excitation
    - Identified model (estimated parameters and uncertainties)