AERO 2-DOF Helicopter Model Identification Experiment Guidelines

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1. Experimental Setup

The AERO helicopter is configured in the "half-quadrotor" mode, i.e., the #0 and #1 motors are facing upward.

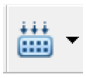
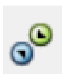
1.1. Experimental Environments

The experiments are conducted via QUARC + Matlab Simulink. The following two files are involved:

"Experiment_AERO_pitch_channel_identification.mdl" Running the experiments and logging the results

"Parameters_and_initial_conditions.m" Configuring the experimental environments, parameters and initial conditions.

1.2. Running the Experimental Programs

First, open the Simulink model "Experiment_AERO_pitch_channel_identification.mdl" and click on  to build the model. Second, click on  to connect to the AERO helicopter. Then click on  to run the experiment.

Note that every time the Simulink model "Experiment_AERO_pitch_channel_identification.mdl" is modified, rebuild the model before connecting to the helicopter. Otherwise (even though the parameters in the configuration file "Parameters_and_initial_conditions.m" are changed), the experiment can be repeated without rebuilding the model.

2. Helicopter Model Identification

2.1. The Pitch-channel Model

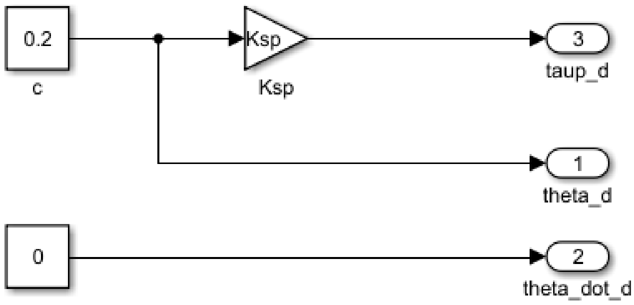
The linear time-invariant model of the AERO helicopter pitch-channel motion is

$$J_p\ddot{\theta} + D_p\dot{\theta} + K_{sp}\theta = \tau_p$$
$$\tau_p = K_{pp}V_p$$

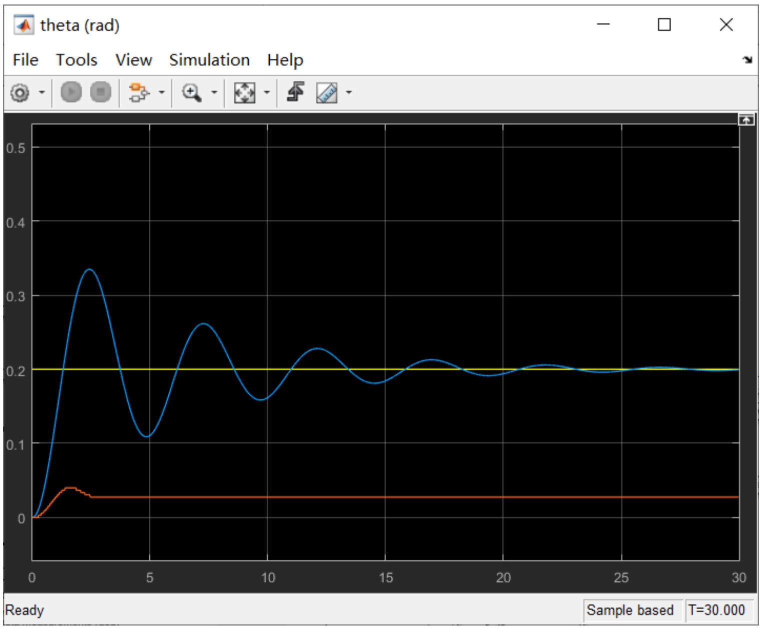
where θ is the pitch angle, τ_p is the control torque, V_p is the voltage applied to the #0 motor, other coefficients are provided in the user manual: $J_p = 0.02189$, $D_p = 0.0071116$, $K_{sp} = 0.037463$, and $K_{pp} = 0.0011$. However the values are for the "helicopter" mode, i.e. the #0 motor faces upward while the #1 motor faces sideward. Therefore we need to identify the damping coefficient D_p, the stiffness coefficient K_{sp}, and the torque-to-voltage coefficient K_{pp} for the "half-quadrotor" mode.

2.2. Model Identification around a Certain Equilibrium

Consider the equilibrium point $\theta_e = 0.2\ rad$. It is readily obtained that $\tau_e = K_{sp}\theta_e = K_{pp}V_{pe}$. Setup the reference system in the block Experiment_AERO_pitch_channel_identification ▶ Reference ▶ const c as



where the constant reference c is set to be $c = \theta_e = 0.2$. The initial values of the identified coefficients are $D_p = 0.0071116$, $K_{sp} = 0.037463$, and $K_{pp} = 0.0011$. And after running the program, we can correct these values according to the experimental results. The first experimental result is shown below, where the yellow curve is the reference (equilibrium point), the red curve is the real response of the helicopter, and the blue curve is the simulated response generated by the helicopter mathematic model with the aforementioned coefficients.

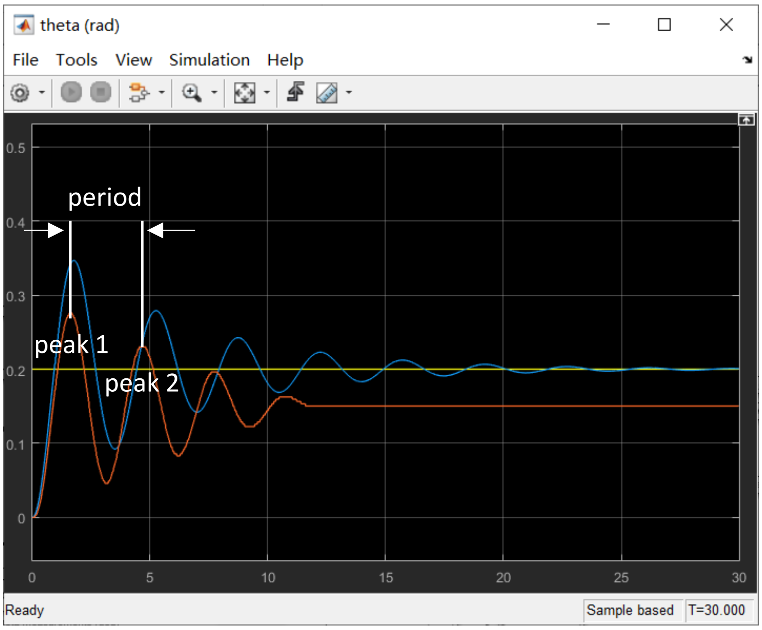


Obviously, the mathematic model is not in line with the real model. Therefore we need to adjust the coefficients to better describe the real physics.

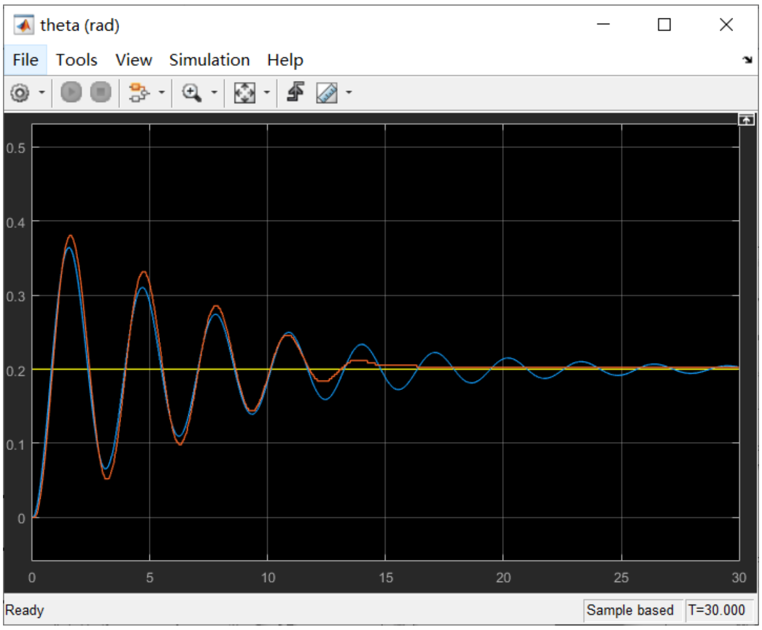
The guidelines for adjusting these coefficients are summarized as follows, where the definitions of peak 1, peak 2 and period are specified in the following figure.

1. Increase D_p to enlarge the amplitude difference between peak 1 and peak 2;
2. Increase K_{sp} to reduce the period (time difference between two peaks);

3. Increase K_{pp} to reduce the final value (steady-state) of θ.



By carefully adjusting the coefficients, we can obtain the following results: $D_p = 0.0056$, $K_{sp} = 0.09$, and $K_{pp} = 0.00109$, which approximately fit the real response, as shown in the figure below:



It is observed that D_p and K_{sp} are very different between "half-quadrotor" mode and "helicopter" mode.

2.3. Modeling Based on Multiple Equilibriums and Model Simplification

We can follow the identification procedure provided in the previous section to repeat the experiments and obtain the coefficients around different equilibriums. Then the helicopter pitch-channel motion can be modeled by a piecewise function with different coefficients.

However, this will make the model discontinuous and time-variant, which adds difficulty to the control design. Therefore we usually use one set of coefficients around a certain equilibrium to describe the helicopter model when designing the controller, and the coefficients are selected according to the control profiles (such as the working ranges, control objectives, or the reference pitch angle trajectories). For instance, if the control profile is to track a reference of $\theta_d = 0.2 + 0.1\sin(t)\,rad$, then it is reasonable to use the coefficients identified around $\theta_e = 0.2\,rad$ for the modeling.

3. Actuator Model Identification

3.1. Actuator Modelling

In the user manual, the actuator is modeled by the following linear function

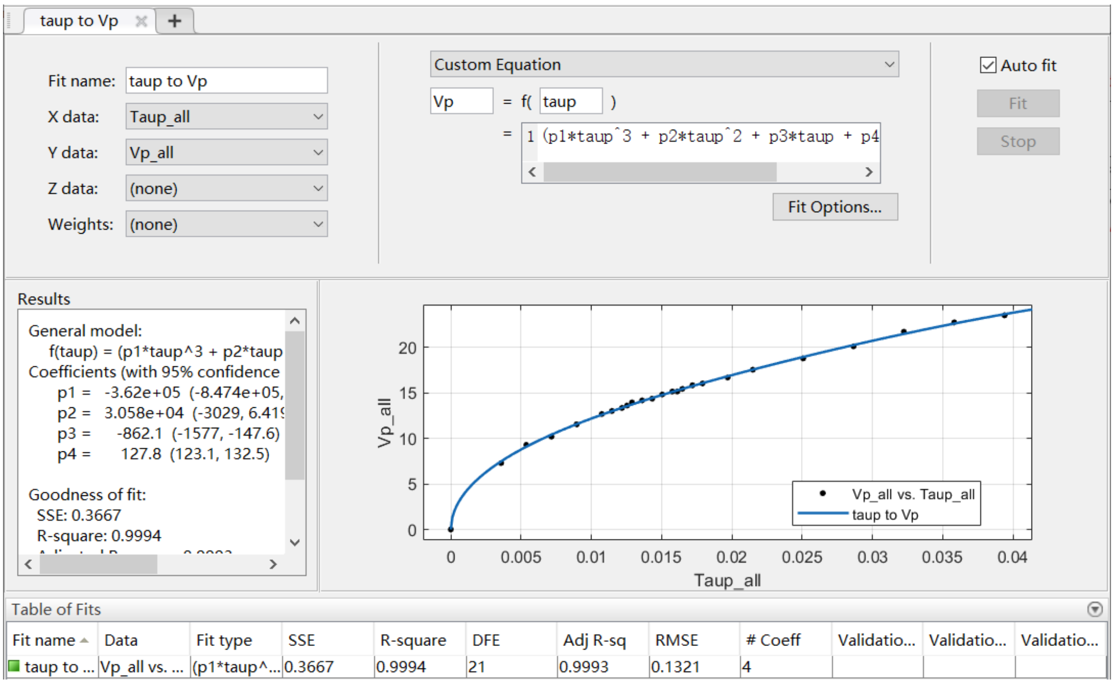
$$\tau_p = K_{pp}V_p$$

However, this function cannot precisely describe the actuator model due to the nonlinearity in the thrust and rotation speed relationship. Thus in what follows we will use the results of the helicopter model identification (discussed in the previous section) to construct a better model for the actuator. Since during the identification procedure for the helicopter around a certain equilibrium, we collected the following data: τ_p and V_p. Then it's possible for us to repeat the experiments around different equilibriums and collect the corresponding set (τ_p, V_p). After collecting sufficient data which cover the working range of the helicopter, we can then use the curve fitting technique to obtain the torque-voltage relationship $V_p = f_{\tau 2V}(\tau_p)$.

3.2. Actuator Model Identification by Curve Fitting

Use the Matlab curve fitting toolbox, and import the collected data, we get the following fitting results. Here we select the following nonlinear function

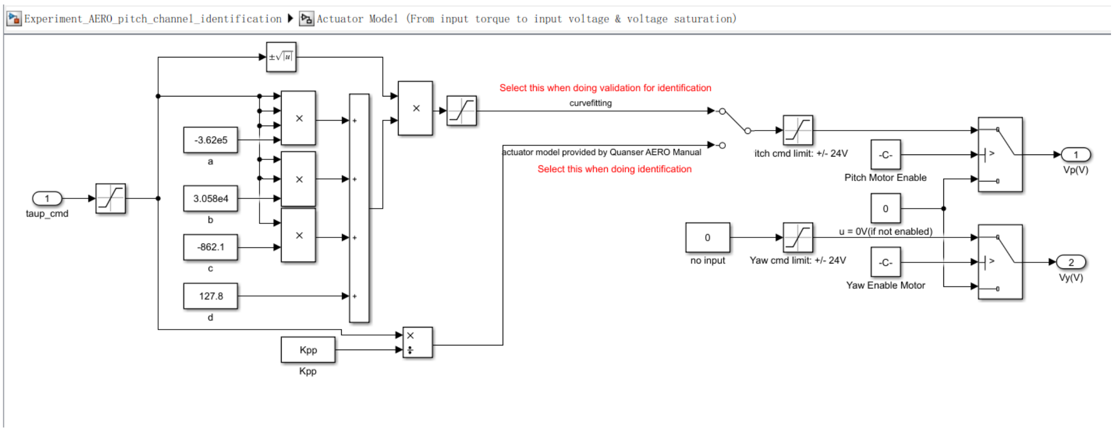
$$V_p = (p_1\tau_p^3 + p_2\tau_p^2 + p_3\tau_p + p_4)\sqrt{\tau_p}$$

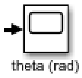


Then we obtain the fitting results: $p_1 = -3.62 \times 10^5, p_2 = 3.058 \times 10^4, p_3 = -862.1, p_4 = 127.8$.

3.3. Actuator Model Verification

After the model identification, we can verify the obtained nonlinear function by applying it to the helicopter. In the “Actuator Model (From input torque to input voltage & voltage saturation)” block in the Simulink model, double-click on the “manual switch” to switch to the curvefitting function, as shown in the figure below.



Then, apply any reference signal to the “Reference” block and run the program. Check the blue and red curves in the theta responses scope 

. If the two curves overlap, the curve fitting is satisfactory. Otherwise, collect more samples (τ_p, V_p) around different equilibriums and redo the curve fitting.