ACO Assignment – January 2022

MSc in Automotive Mechatronics and MSc in Advanced Motorsport Mechatronics

Introduction

Connected and automated vehicles rely on a good picture of the output environment. This can come from a variety of sensors, and we are living in a rapidly evolving world so it is likely that more sensors will be developed in future.

Some types of sensor are mounted so they can move on a vehicle and either 'scan' a wide field of view or be directed at a specific feature of interest. Another example is 'satcom on the move' – see https://www.youtube.com/watch?v=Klj3k2lSBW4 for a good example from EM Solutions in Australia.

A traditional mount for such a sensor pivots in at least two axes – a base rotation called 'azimuth' mathematically followed by a vertical rotation called 'elevation'. (These names come from astronomy.) Azimuth is usually represented by the Greek letter γ (gamma); elevation is represented by the Greek letter α (alpha).

As well as inertial effects, systems like this are subject to friction and damping, as well as the inevitable disturbances and noise. Sometimes, geometric changes can alter the inertial configuration too.

In this exercise, you will design a feedback control system to steer a sensor system like this, rejecting the effects of noise, disturbances and modelling unknowns. You will try a number of different methods, and you will have an opportunity to make observations about the relative merits of each methods.

What you get

We are giving you some MATLAB and Simulink files. The main one – which starts with 'm01_' is a system model including the plant. Don't change this, but do use it as a starting point. You also get some useful library files, data files, and a version of the model starting with 'm02_' that can be used for trimming and linearization.

You also have access to us via the discussion forum and we'll be scheduling some sessions – all this is for formative feedback. (Note that we don't do one-to-one sessions and we don't answer questions by email – we're aiming to give everyone the benefit of the same help.)

What you need to do

You need to provide a write-up answering the questions below.

Please include page numbers, and please put your student number on the front page. Please don't put your name on the front page – we mark anonymously as far as possible.

Please follow any instructions from Student and Academic Support to the letter, particularly in the unlikely event of problems. We have very limited discretion when people don't follow the instructions.

Please keep your report as short as possible. The right length is 'long enough, but not a word longer'. Aim for clarity, readability, saliency and brevity.

The questions

Q1. Provide a written explanation of the model, including discussions of the following aspects:

i. The physical quantities represented by the model's states.

ii. The linearity of the core 'plant model' component – if you find it is nonlinear, identify specific nonlinear elements in the model; where practicable, demonstrate any nonlinearities' effects in simulation.

iii. The presence (or otherwise) of cross-coupling between the azimuth and elevation parts of the model.

iv. The presence of noise/disturbances in the model, and – if present – their frequency domain characteristics.

[10 marks]

Q2. Write a MATLAB program to linearize the model (using the version of the model that has all the 'extras' removed, 'm02_linearization_model') and include this and its outputs in your report. Include discussion of the following:

i. The code you write to trim and linearize the model, including a listing.

ii. The steady-state state and input, and the state-space system you get.

iii. A comparison between the time domain behaviour of the linearized model and the original Simulink plant model, showing how well they match and whether there are any differences as azimuth and elevation change.

iv. Screenshots for the model used for comparison in (iii) and its outputs.

Note that if you are unable to solve this question, numerical results are available in MATLAB data files which can be used without penalty for Q3 onwards. The results have been annotated to ensure that we can tell you have done this – this will hopefully prevent anyone less scrupulous than yourself avoid the temptation to 'fudge' this question!

[20 marks]

Q3. Use the H-infinity loop-shaping method to design a controller to achieve the fastest and most accurate responses you can without an unreasonable element of noise manifesting itself in the control signal. Include discussion of the following:

i. The choices you make regarding setting the system bandwidth and the frequency weighting you use.

ii. Singular value plots for your plant, weighted plant and robustified loop gain, with annotations showing the effects of your weights and the effects of the H-infinity synthesis step.

iii. The achieved sensitivity and complementary sensitivity plots.

iv. The weighted robust stability margin you achieve.

v. Time domain plots from Simulink, including control signals.

vi. A discussion of the results you get, the effects of any nonlinearities (where applicable), and discussions trade-offs and refinements you made.

[20 marks]

Q4. Use the mixed sensitivity method to design a controller to achieve the fastest and most accurate responses you can without an unreasonable element of noise entering manifesting itself in the control signal. Include discussion of the following:

i. The choices you make regarding setting the system bandwidth and the frequency weighting you use.

ii. Singular value plots for your plant, weighted plant and robustified loop gain, with annotations showing the effects of your weights and the effects of the H-infinity synthesis step.

iii. The achieved sensitivity and complementary sensitivity plots.

iv. A discussion as to which of the three weights has most effects in your design.

v. Time domain plots from Simulink, including control signals.

vi. A discussion of the results you get, the effects of any nonlinearities (where applicable), and discussions trade-offs and refinements you made.

[20 marks]

Q5. A reduced-complexity version of the state-space model is available in the data directory. Please use this for this question, as it is quite difficult without it.

Using a state feedback method of your choice, design a state feedback controller with an observer to achieve the fastest and most accurate responses you can without an unreasonable element of noise entering manifesting itself in the control signal. Include discussion of the following:

i. The choices you make regarding pole locations, gains and/or weight values use.

ii. Pole-zero plots for your plant and controller

iii. Time domain plots from Simulink, including control signals and the accuracy of your observer.

iv. A discussion of the results you get, the effects of any nonlinearities (where applicable), and discussions trade-offs and refinements you made.

[20 marks]

Q6. Discuss the effectiveness, advantages and disadvantages of the methods you have used, including the following aspects:

i. Ease of application – you can consider both the initial learning curve and your level of competence by the end of the exercise if they differ.

ii. Design robustness.

iii. Ease of fine-tuning and refinement.

iv. Effectiveness in dealing with nonlinearities and constraints.

v. General suitability for controlling this system.

We're not looking for sweeping generalizations here. We are looking for things you can argue based on your experiences in this design exercise and – if applicable – elsewhere.

You may also consider whether other methods introduced in the course might be equally or more appropriate.

[10 marks]

