CADE20002 Dynamics and Control of Linear Systems
Academic year 2024-2025 coursework specification, Signals, Systems and Control

Release: 13:00, Thursday 20 March 2024.
Due: 13:00, Thursday 27 March 2024. Institutional policies and penalties apply.
Submission: Single PDF report plus single .zip file of code.
Guideline workload: 1 working day (7h), although you are not constrained to this and are not expected to complete in one sitting.
Maximum length: 6 pages.

This coursework consists of four questions across two sections – mark these clearly in your submission as each section will be assessed separately.

Marks (total=100) in brackets after each question are a guideline for response time and length. Assessment will be against the rubric attached, which is benchmarked against University marking criteria – level 5.

This assessment is 'open book' and you are free to use any resources at your disposal, however work should be undertaken individually. Cite and reference sources in your preferred format. Institutional plagiarism detection and penalties apply.

AI/LLM usage is permitted under 'Category 2: Minimal' regulations, however caution is advised regarding its use. You are accountable for all content in your submission, and should include a boxed 'academic integrity' statement at the start of your work outlining any/no usage and its scope, which **MUST** include an acknowledgement of accountability for the work, e.g.:

Academic integrity statement (example): Anthropic's Claude 3.5 Sonnet was used to proof and condense sections 2 and 3 of this work. No AI was used for data analysis or figure generation. The author has considered and included several suggested references and is fully accountable for the submitted work.

Submission instructions:

~~Submit your report to the **SSC Coursework Turnitin** submission point as a single PDF. Submit your code and/or models to the **SSC Coursework Code** submission point as two folders (named `section A` and `section B`) within a single .zip file (named with your username e.g. `ab21456.zip`) such that they may be run on any university MATLAB PC and will output all data and figures used in your submission.~~

Combine your answers to this Signals, Systems and Control theme coursework with your answers to the Vibrations and Aeroelasticity theme coursework, into a single report submission.
Structure this single submission in the following order: 1) Answers to the V&A theme; 2) Appendix of code used in the V&A theme; 3) Answers to SS&C theme; 4) Appendix of code used in the SS&C theme.
Submit your report to the 'Individual Report (Submission Point)' on Blackboard.

Context

Low Earth Orbiting Observation Satellites (Terra & Aqua) are important for monitoring our planet's systems from Low Earth Orbit (LEO). These spacecrafts feature large deployable solar arrays and antennas, which are flexible appendages attached to a rigid central body. They also carry instruments with active mirror scan mechanisms, such as the Moderate Resolution Imaging Spectroradiometer (MODIS).

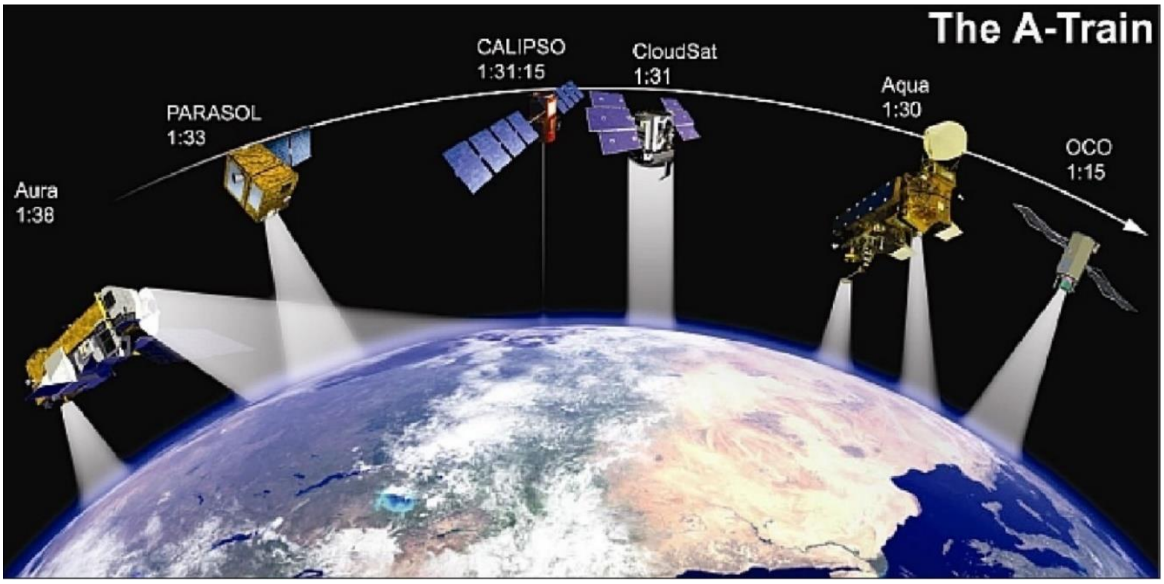

Figure 1: Illustration of the Aqua Earth Observation Mission (image credit: NASA)

Recently, operators of one of these satellites have encountered an anomaly in the operation. The unexpected behaviour is potentially compromising the quality of scientific data being collected. As experts in spacecraft dynamics and control, we have been called upon to assist in diagnosing this issue. This involves analysing telemetry data, examining the system's frequency response.

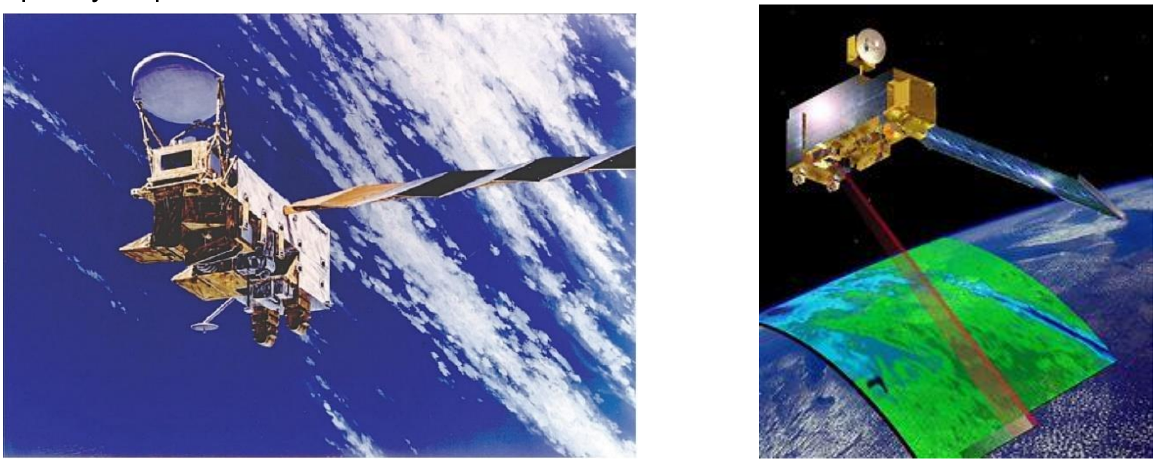

Figure 2: Illustration of the Terra & Aqua satellite (image credit: NASA)

After this, we will control the satellite before hand-over. The challenge lies in ensuring stable pointing while managing the dynamic interactions between the rigid body and flexible structures.

Section A
An experiment to characterise the behaviour of a control system on the spacecraft is running into difficulties. You have offered to help work out what is wrong.

1. You are told that during the first test the spacecraft system is driven by several signals which take the form of a triangular variation around different offsets. The signals are produced by a signal generator and then amplified as shown in Fig. 3. The output from the signal generator is known to be correct, but there are suspicions regarding the output of the amplifier. You are provided with three signals recorded at the output of the amplifier; these can be found in the file '`test_signals_part_a.mat`'. The signal has units of volts, and the time is recorded in seconds.

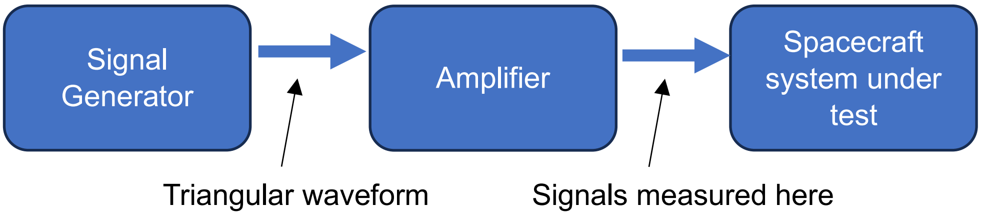

Figure 3: Test arrangement

a) Calculate as many time domain metrics for the three signals as you think are relevant to understanding the system behaviour. Justify your effort by briefly describing what you could learn from each, noting what information about the signals you have and what is unknown.

(10)

b) With reference to your results from part a), what can you conclude about each of the signals?

(10)

c) Suggest a physical cause for any behaviours you have deduced from your investigation of the signals.

(5)

2. During a sperate experiment the system under test is driven by a different periodic signal and recorded in file '`test_signal_part_b.mat`'. The data captured is not what the test engineers were expecting, and you offer to help make sense of it. As before, the signal has units of volts, and the time is recorded in seconds.

a) Plot the recorded signal in the time domain. Perform an FFT on the signal and plot the single-sided magnitude spectrum. Correctly label both axes of your figures and briefly describe how you scaled both the magnitude and frequency axis of the frequency spectrum plot.

(10)

b) Identify as many features from the time domain plot and magnitude spectrum as you can.

(5)

c) The harmonic components of the magnitude spectrum do not make sense to the test engineer – they do not follow the pattern expected. Suggest why the harmonic components appear where they are and thus determine the true time domain waveform of the test signal.

(10)

3. The spacecraft system under test is the scanning mirror of an optical system. The output of the amplifier is converted to a force with 1V = 1N, and applied to the mirror mechanism which has a mass of 20 grams and rests on a linear bearing with damping 9.4 Ns/m.

a) Sketch the bode plot of the mirror system for force input / position output. Show / explain all steps you took to produce the plot.

(10)

b) If the amplifier output is a 100 Hz square wave, with amplitude ± 5 V, what is the maximum excursion of the mirror? Show / explain all steps you took to calculate the result.

(10)

4. Control Design for LEO Satellite with Flexible Appendages

You are asked to design pitch controller for the LEO satellite with flexible appendages. Operators are provided the models including two dominant flexible modes. The transfer function and block diagram of the pitch attitude dynamics, with rigid body moment of inertia of $J = 1000\ \mathrm{kgm}^2$, are shown in Figure 4.

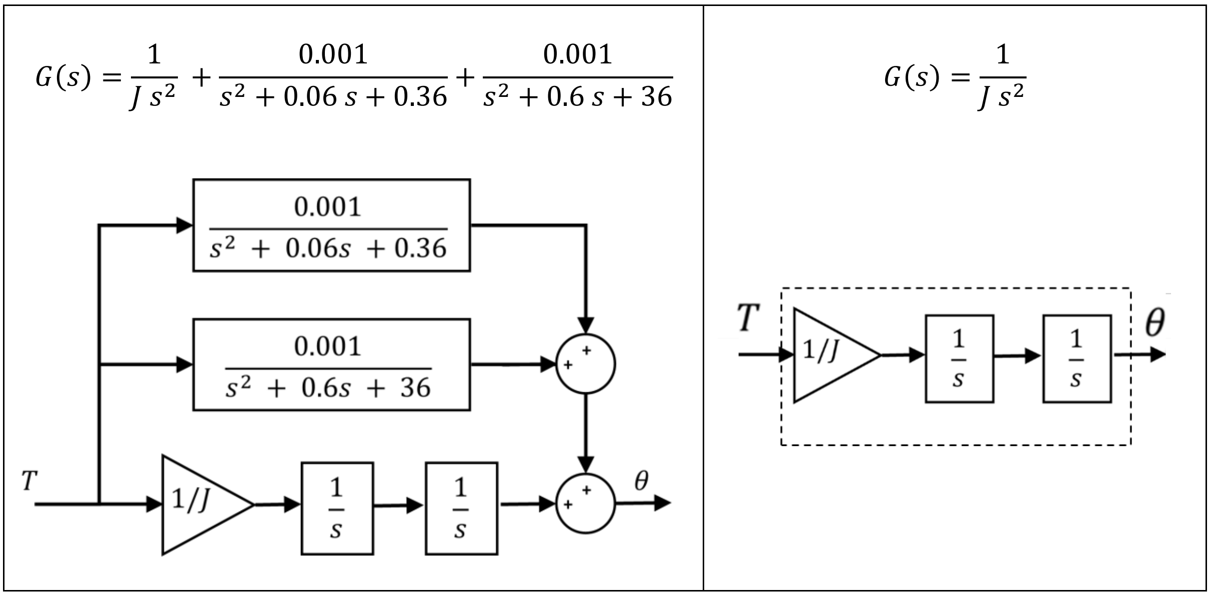

Figure 4: LEO satellite open-loop system (left) and simplified approximation (right)

You are asked to design two pitch controllers for the **simplified approximation** of the spacecraft to **track a reference input of** $\theta = 1.0\ \mathrm{rad}$ and to test their performance against the **full open-loop system**, in order to stabilise against slowly varying (large period) environmental disturbances whilst minimising the excitation of flexible modes.

a) Proportional with Rate Feedback Controller
b) PD Controller

Guidance:

- This problem is known as control-structure interaction problem. This issue can be handled by designing an attitude control system with a proper bandwidth.
- It is suggested that you design these controllers in order to achieve a **natural frequency of the closed loop system** $\omega_n = 0.06\ \mathrm{rad/s}$ and **damping ratio** $\zeta = 0.707$.

Reporting:

- While designing the controllers, explain your design approach and justify parameters.
- Please keep in mind that you should **design** your controllers against the **simplified system** but **evaluate** them against the **original system**.
- Compare the performance of the two controllers by considering and justifying the appropriate metrics.
- Provide detailed explanations and graphical representations to support and critique your analysis.

(30)

Appendix: CADE20002 assessment rubric, benchmarked against University marking criteria – level 5.

Marks	**0, 7, 15**	**22, 29, 35**	**42, 45, 48**	**52, 55, 58**	**62, 65, 68**	**72, 75, 78**	**83, 94, 100**
Methodological approach and accuracy (40%)	Major inaccuracies, limited understanding of taught content, applied poorly.	Gaps in knowledge, Superficial understanding of concepts, applied to problem with some errors. Limited evidence of additional understanding.	Sufficient knowledge and understanding to deal with well-established principles of taught content. Some critique and awareness of limitations.	Broad knowledge, Good use of taught material in addressing problems. Awareness of boundaries and limitations.	Coherent use of taught material to approach problems in a systematic way. Few to no errors.	Comprehensive, systematic, and appropriate application of taught concepts, with very good, detailed understanding of material, main concepts/theories at this level. Almost no errors	Fluent, elegant, and accomplished selection and application of taught concepts, with highly detailed understanding of material, main concepts/theories at this level. No errors.
Argument and critique (30%)	Lacking in coherence, difficult or impossible to follow.	No evidence of critique, poor justification of approach to problem and/or analysis.	Little evidence of critique, or logic contains flaws that show limitations in understanding or awareness of context.	Limited evidence of a critical approach to the knowledge base but logic behind methodology and analysis is easy to follow.	Clear evidence of a critical approach to the knowledge base with some understanding of the implications of these limitations for application and analysis.	Shows good explanation and justification of approaches, and reasoning behind outcomes. Coherent and substantiated arguments, including a range of considerations.	Consistent and very good awareness of the limitations of the knowledge base and how this influences any analyses and interpretations based on that knowledge.
Explanation and communication (30%)	Difficult for reader to understand approach or findings. Inappropriate or no use of tables, figures, etc.	Weak writing, challenging to follow. Inconsistent formatting of text and/or figures, which may be hard to understand.	Writing generally clear, with an appropriate tone. Some minor inconsistencies or issues with clarity, but approach can be followed by the reader.	Clear and consistent writing and explanation throughout, with data and analysis presented in appropriate manners.	Written and presented thoroughly and clearly, with appropriate use of figures and tables as required by the material.	Well-presented, with fluent explanations including appropriate elements to aid the reader's comprehension of approach, results, and analysis.	Exceptionally- well explained and presented, exhibiting insightful and helpful use of a range of elements to aid the reader's comprehension in an elegant manner.