EGB242 – Assignment 2 (35%)

Group assignment

Released: Friday 26th April, 11:59 pm (Week 8)

Due: Friday 24th May, 11:59 pm (Week 12)

Context

Given the overwhelming success of the communication system during your first placement within BASA during Assignment 1, you have been placed in the main engineering team of three for the crewed Mars mission.

Preparation

To generate the data required to complete Assignment 2, you must populate and run the startHere.m **script.** Follow the instructions contained within the file to generate DataA2.mat.

Template files (missionA2S1.m, missionA2S2.m, and missionA2S3.m) have been provided in which you should write your MATLAB solutions.

Section 1: De-noising the Communication Channel

The communication system you have designed in Assignment 1 has been integrated into the spacecraft headed for Mars. The radio transmitter and receiver are working as intended in transmitting messages back and forth between BASA HQ and the spacecraft. As the craft exits Earth's atmosphere, the received audio begins to become inaudible. Although your original channel provided an accurate model for terrestrial communications, it did not account for distortion of the signal by the atmosphere.

A colleague has produced a general model for the channel which better represents the true transmission conditions (Figure 1). Atmospheric distortions can be modelled as frequency-dependant distortions of the signal (i.e., an LTI system). In addition to atmospheric distortions, single-frequency tones are present in the channel and are being added to the audio signals (i.e., additive noise). It is your role to characterise and then reverse each of these noise processes. A recording of the multiplexed audio signal received over the communication channel, including the received signal distortions is provided in DataA2.mat.

1.1 The recording of the multiplexed audio signal is stored as audioMultiplexNoisy, which was sampled at the frequency stored as fs. Plot the multiplexed audio signal in both the time and frequency domain.

1.2 Using the de-multiplexing system developed in your first assignment, locate the carrier frequencies of each modulated audio signal and demodulate each of the audio streams. Listen to each of these demodulated audio signals and comment on how the audio sounds. Plot each of these demodulated audio signals in both the time and frequency domain. Can you identify any features of the demodulated audio signals which may be caused by the noising process modelled in Figure 1?

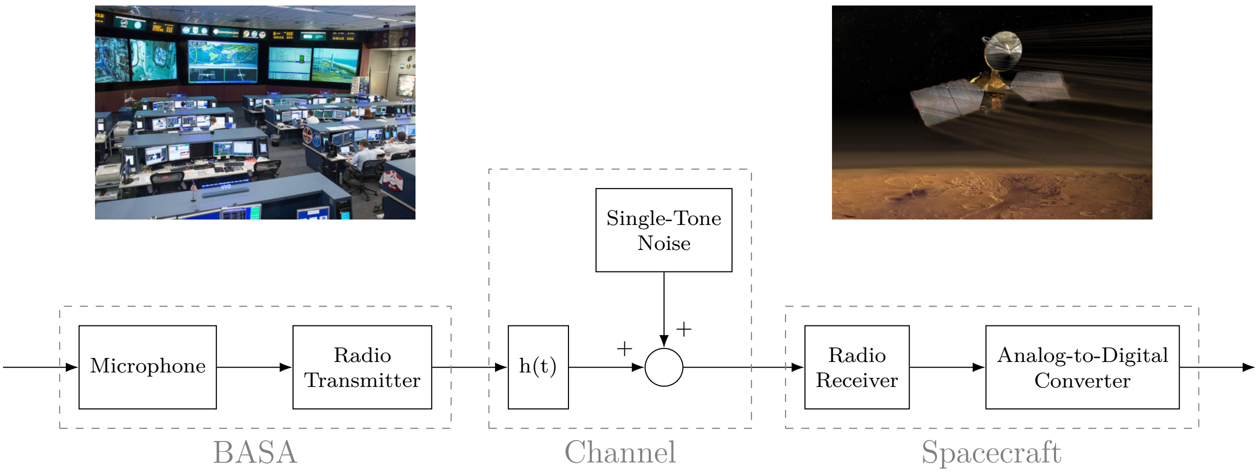


Figure 1: The communication system implemented in Assignment 1 with the channel noise that is introduced as a result of transmitting the audio signal through Earth's atmosphere and space.

1.3 Model the frequency-dependant distortion. You can transmit any signal through the channel by using the channel.p function. The channel acts as an LTI system where the received signal $y(t)$ is the convolution of the transmitted signal $x(t)$ with the impulse response of the channel $h(t)$. **Note that the** sid **variable has already been loaded into your workspace.**

y = channel(sid, x, fs);

Select and transmit a test signal through the channel which will allow you to model the impulse response of the channel. Why does the signal you chose allow you to reproduce the impulse response of the channel? Provide a mathematical justification for this choice.

Plot the frequency response of the channel $H(f)$ and the magnitude spectrum of the multiplexed audio signal audioMultiplexNoisy on the same set of axes. From this comparison, identify any additional features which may be caused by the noising process.

1.4 Use the model of the frequency-dependant channel distortion to reverse this distortion on the multiplexed audio signal. Repeat the demodulation procedure and listen to the de-noised audio. Is there still noise present? Plot the time and frequency domain of the de-noised audio and identify any remaining noise in the audio signals.

1.5 Determine the frequency of the remaining single-tone noise in the recorded audio signal and remove it in the frequency domain. Listen to the fully de-noised audio signal and plot the final signal in the time and frequency domain.

Section 2: Rover Camera Control

When the spacecraft arrives on Mars, the astronauts will first need to send a Mars rover to locate a suitable landing location. This Mars rover will travel to a number of candidate landing sites and transmit images of these sites back to the spaceship so that the astronauts can choose a safe location to touch down. Integral to capturing images of the Mars landscape is the ability of the rover's camera to rotate on its yaw angle to pan the landscape.

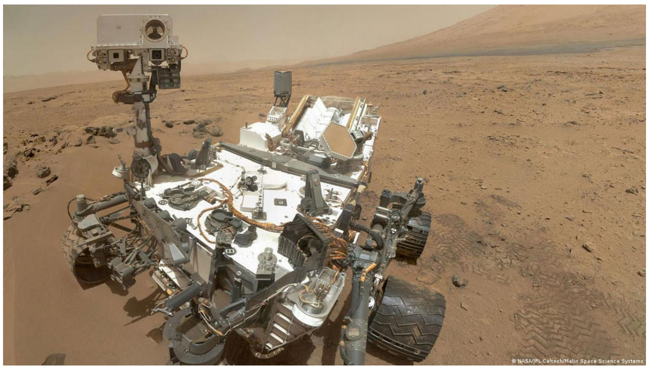


Figure 2: Image of the Mars rover and its camera. The camera can capture images of the surrounding landscape by rotating the yaw angle $\psi(t)$ of the camera.

You have been given the task of modelling a control system for a servo motor controlling the rotation of the camera's yaw angle $\psi(t)$ in radians. This servo motor is to be controlled by an input voltage signal $v_{in}(t)$ which ranges between 0 and 1 V and is relayed from the spacecraft. This input voltage range should allow a 0 to 2π rad rotation of the yaw angle $\psi(t)$ – that is, at maximum, one full rotation.

2.1 A DC motor is an electro-mechanical system which rotates an axle shaft with an angular velocity proportional to the input voltage. Treated as an LTI system, the DC motor can be modelled in the Laplace domain as:

$$V_{in}(s) \longrightarrow \boxed{\begin{array}{c}\text{Motor and load}\\ G_m(s)\end{array}} \longrightarrow \Psi_{out}(s)$$

$$G_m(s) = \frac{\Psi_{out}(s)}{V_{in}(s)} = \frac{K_m}{s(s+\alpha)}$$

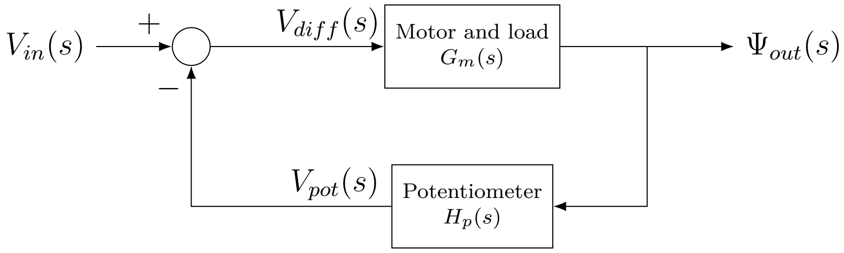
Given the motor's design which sets $K_m = 1$ and $\alpha = 0.5$, use your knowledge of Laplace transforms to find the step response of the system, showing all hand working. Create a time vector over the interval $t \in [0, 20)$ seconds with 10^4 samples and plot a comparison between the step input and step response.

Given that a constant input voltage should cause the camera's yaw to converge on a constant angle, is the motor alone sufficient to control the angle of the camera?

2.2 Your supervisor with experience in control systems suggests coupling a potentiometer to the motor's axle to generate a voltage $v_{pot}(t)$ proportional to the angular displacement of the camera, namely:

$$H_p(s) = \frac{V_{pot}(s)}{\Psi_{out}(s)} = K_{pot}$$

This potentiometer voltage can be used to give feedback in the system about the current angular displacement of the camera and so your supervisor suggests to instead drive the motor with the difference between the input voltage $v_{in}(t)$ and the potentiometer voltage $v_{pot}(t)$:



Model the transfer function $F(s) = \dfrac{\Psi(s)}{V_{in}(s)}$ of the system with this feedback circuit if $K_{pot} = 1$. What order is the transfer function for the system? What are the poles of the transfer function?

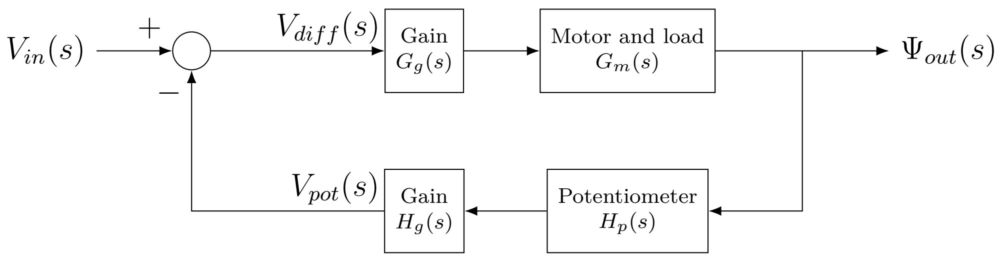
Input this model of the feedback circuit into MATLAB using a tf object. Using the lsim function in MATLAB, plot the step response of the feedback system using the same time vector as in 2.1. Explain what has changed after adding the feedback circuit that now makes it more appropriate for controlling the camera's angular displacement than the system without feedback.

Hint: If you first find the transfer function in terms of $H_p(s)$ and $G_m(s)$ it will allow you to rearrange the transfer function more easily before substituting these blocks. The transfer function before this substitution should have $\Psi_{out}(s)/V_{in}(s)$ be a function of only $G_m(s)$ and $H_p(s)$.

2.3 Find the natural frequency ω_n and damping ratio ζ of the feedback circuit and state which damping case applies for the system (i.e., overdamped, underdamped, undamped, or critically damped). Using these values, determine the time to peak T_p, settling time T_s, and percentage overshoot $\%OS$ of the system.

Why is the feedback system still not appropriate for controlling the camera's angular displacement? Recall that $0 \leq v_{\text{in}}(t) \leq 1$ V and $0 \leq \psi(t) \leq 2\pi$ rad.

2.4 Given your concerns, your supervisor suggests adding gain circuits to the control circuit as shown below: where $G_g(s) = K_{fwd}$ and $H_g(s) = K_{fb}$.



Incorporate these gain blocks into your transfer function. Create another transfer function object in MATLAB and investigate how changing each block's gain affects the step response of the system. To investigate the effect of K_{fb}, simulate and plot the step response of the system when K_{fb} takes the values of $\{0.1, 0.2, 0.5, 1, 2\}$ and $K_{fwd} = 1$. Repeat this analysis with K_{fwd} for $\{0.1, 0.2, 0.5, 1, 2\}$ and $K_{fb} = 1$.

2.5 The camera on board the Mars rover is going to be used for sweeping panoramas of the Mars landscape. In these panoramas, the rover's camera must sweep between two angles in a controlled motion. This means that the camera control system you have designed must be able to:

- Accurately rotate to any angle (i.e., from 0 to 2π rad) from the range of input voltages.
- Not rotate too quickly during the pan, or else the images will become blurred. To limit the angular velocity of the camera, set the time to peak to 13 seconds (i.e., $T_p = 13$ s).

From the formulas used to find the system parameters in 2.3 and the analysis in 2.4, determine the gain values for $G_g(s)$ and $H_g(s)$ which make the camera control system conform to these specifications and store this tf object as cameraTF.

2.6 The Mars rover has now landed on Mars in preparation for the crewed mission. BASA has decided that the first task of the rover is to capture a panorama to orient the Mars rover at the landing site. This panorama is to sweep between camera rotation angles from 30° to 210°. The cameraPan.p function has been provided to provide a live feed of this initial sweep, and can be used as follows:

```
[startIm, finalIm] = cameraPan(startVoltage, endVoltage, cameraTF);
```

The camera will be driven by an input voltage waveform that steps from the startVoltage to the endVoltage (note: not from 0 to 1). The cameraTF variable must be a tf object with the numerator and denominator of the camera control system derived above. A live feed of captured images will be presented during this pan with the $\psi_{out}(t)$ angle (in degrees) overlaid on the top of the image feed. A successful panorama will have a constant stream of in-focus images which pan between the target angles within the target time.

Section 3: Choosing a Landing Site

Your team's design of the control system for the camera onboard the Mars rover has been successful in capturing images of potential landing sites for the crewed mission to Mars. These images have been relayed to BASA's HQ so that a suitable landing site may be chosen.

You have been tasked with filtering out yet more noise which has been introduced to the image signals by the communication channel.

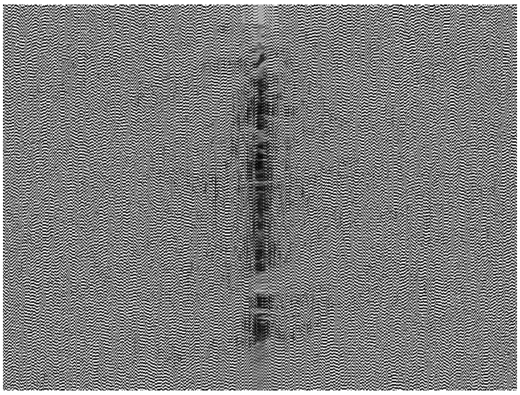


Figure 3: Example noisy image of a potential landing site for the Mars mission.

Images in MATLAB

Images in MATLAB are stored as 2D matrices. Each element in the matrix represents a pixel of the image. The numeric value at each matrix index describes the colour intensity of each pixel. Matrix elements for grayscale images are floating point numbers between 0 and 1; which correspond to the colours black (zero intensity) and white (maximum intensity) respectively. You will be working with grayscale images in this section.

Even though the images are represented by 2D matrices, in the communication channel they are received pixel-wise over time (i.e., as a 1D data stream). The first received pixel is placed at the top left corner of the image. Subsequent pixels are used to fill the image in column-major order (that is, top-to-bottom first, then left-to-right). Each received image is 640 pixels wide and 480 pixels tall.

$$1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10 \quad 11 \quad 12 \longrightarrow \begin{matrix} 1 & 4 & 7 & 10 \\ 2 & 5 & 8 & 11 \\ 3 & 6 & 9 & 12 \end{matrix}$$

The received signals are provided in the rows of the matrix imagesReceived. Four images have been received, with the first stored in the first row of the matrix. To aid your work with image signals your supervisor has provided some useful code examples:

```
% Converting a received pixel stream to an image matrix
im2D = reshape(im1D, numRows, numCols);

% Displaying an image in a figure
figure;
imshow(im2D);

% Saving an image matrix as an image file (to include in report)
imwrite(im2D, 'filename.png');
```

As a proof of concept, you should only work on the first image for 3.1 to 3.4. After demonstrating the functionality of your code, you will be required to repeat these steps for all images and so your code should be properly factorised to allow for these procedures to be repeated easily.

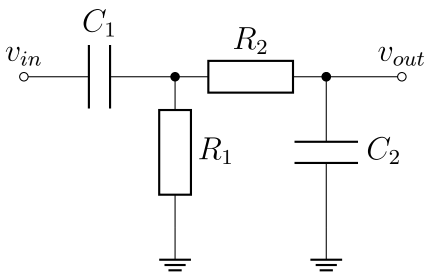
3.1 Display the first received landing site image that has been received from the communication channel and comment on the image quality.

3.2 Image data is received at 1000 pixels/sec and a single sample is taken per pixel. Construct a time and frequency vector for the received signal (i.e., a single image) and store these in t and f, respectively.

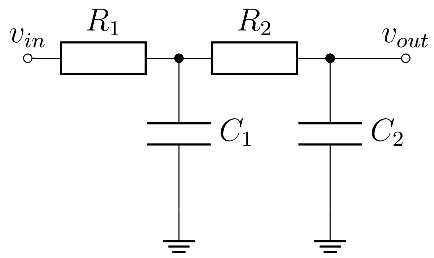
Visualise the received signal in both the time and frequency domains. Describe the components of each representation which are attributable to the desired image signal and to the channel noise. Describe the nature of the noise and identify the frequency range/bandwidth of the noise.

3.3 A filter will be used to remove the noise from the received signal. BASA has a number of filters available for you to choose from. The only information about each of these filters available to you is their circuit diagrams (shown below) and the transfer functions for both active filters. Using your knowledge of LTI system modelling, analyse each of the filters to determine the most appropriate circuit to use.

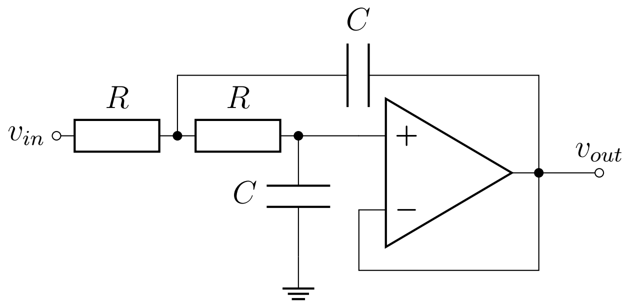
Consider the values $R_1 = 1.2\ \text{k}\Omega,\ C_1 = 10\ \mu\text{F},\ R_2 = 1\ \text{k}\Omega,\ C_2 = 4.7\ \mu\text{F},\ R = 820\ \Omega,\ C = 1\ \mu\text{F}$ in your analysis.



Passive filter 1

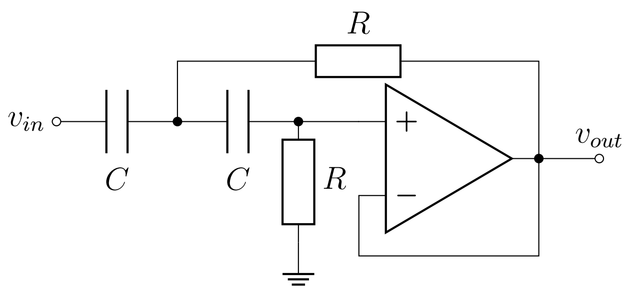


Passive filter 2



Active filter 1

$$\frac{V_{out}}{V_{in}} = \frac{1/(RC)^2}{s^2 + 2s/RC + 1/(RC)^2}$$



Active filter 2

$$\frac{V_{out}}{V_{in}} = \frac{s^2}{s^2 + 2s/RC + 1/(RC)^2}$$

3.4 Use the chosen filter to remove the noise from the received signal and to isolate the clean image. Display the clean image – has the noise been removed? Visualise the now clean image signal in the time and frequency domains.

3.5 Once you have confirmed that the de-noising method is functional, repeat the de-noising process for the remaining images. Display all of the clean, landing site images and provide a recommendation for the MARS-242 landing site.

Reflection

Each group member must write a two paragraph reflection, to be appended at the end of your report. In the first paragraph, summarise how you personally have demonstrated your understanding of the concepts used in this assignment. The second paragraph should be a discussion/professional reflection that covers any lessons learned from doing this assignment, and things that you would have done differently. Marks for the reflection are included as part of the CRA sheet on Canvas.

As this is a personal reflection about your experiences while completing the task, you should use first-person when writing this component.

Submission Requirements

This is an assignment for the purposes of an extension. You should verify this by referencing the unit outline.

There are several components of Assignment 2 which must be submitted to the "Assessment 2 – Group Task: Submission" assignment on Canvas before the due date.

- Your report, in PDF format
- Your complete MATLAB solution (missionA2S1.m, missionA2S2.m, missionA2S3.m)

After submitting, re-download each file to ensure you have submitted a complete and correct version of your assignment.

Group Evaluation

You must individually submit an objective, fair, professional analysis of your group members' performance as a team to the "Assessment 2 – Peer Evaluation: Submission" assignment on Canvas before the due date. A template for your analysis has been provided within the Assignment 2 zip file.

Report

To present your solution to the assignment tasks, you are required to write ONE report.

Your report should demonstrate clear knowledge and understanding of the subject through a combination of visual, mathematical, and coding elements. Your report should have a logical flow which guides the reader through your solution process, incorporating relevant explanations and justifications for the steps taken. Correct information which is not articulated clearly will be awarded a lower grade, as will inaccurate or vague justification. Ensure you include, at minimum, all requested plots/figures and justification. **Remember that you are writing to inform.**

It is highly recommended to follow the below report structure. You may adapt the structure to suit your needs, but ensure you include all required aspects.

- Title page – *must state your group number, group member names and student numbers, the unit name and unit code*
- Introduction
- *Further headings, splitting up your solution as appropriate*
- Conclusion
- Reflection
- References – *if required*
- Appendices
  1. Full MATLAB source code – *include only raw source code, no figures*
  2. *Any other appendices as appropriate*

Note:

- Do not include a table of contents, a list of figures, or a list of tables.
- Integrate code and figures throughout your report. Do not simply state “refer to appendix”.

Interview

You may be selected and contacted to attend an interview if the teaching team requires clarification about how you arrived at your solutions. Interviews will be a casual discussion. These interviews are compulsory and grades are withheld until they are completed. Marks may be deducted for poor demonstration of understanding of content or assignment knowledge. Consult the CRA sheet on Canvas for the guidelines of what is expected.