

Homework 1

AMATH 482/582, Winter 2024

Assigned Jan 12, 2024. Due on Jan 25, 2024 at midnight.

DIRECTIONS, REMINDERS AND POLICIES

Read these instructions carefully:

- **You are required to upload a PDF report to Canvas along with a zip of your code.**
- The report should be a maximum of 6 pages long with references included. Minimum font size 10pts and margins of at least 1inch on A4 or standard letter size paper.
- Do not include your code in the report. Simply create a zip file of your main scripts and functions, without figures or data sets included, and upload the zip file to Canvas.
- Your report should be formatted as follows:
 - Title/author/abstract: Title, author/address lines, and short (100 words or less) abstract. This is not meant to be a separate title page.
 - Sec. 1. Introduction and Overview
 - Sec. 2. Theoretical Background
 - Sec. 3. Algorithm Implementation and Development
 - Sec. 4. Computational Results
 - Sec. 5. Summary and Conclusions
 - Acknowledgments (no more than four or five lines, also see the point below on collaborations)
 - References
- \LaTeX (Overleaf is a great option) is recommended to prepare your reports. A template is provided on Canvas in Homework/Files. You are also welcome to use Microsoft Word or any other software that properly typesets mathematical equations and properly allows you to include figures.
- Collaborations are encouraged, however, everything that is handed in (both your report and your code) should be your work. You are welcome to discuss your assignments with your peers and seek their advice but these should be clearly stated in the acknowledgments section of your reports. This also includes any significant help or suggestions from the TAs or any other faculty in the university. You don't need to give all the details of the help you received, just a sentence or two.
- Your homework will be graded based on how completely you solved it as well as neatness and little things like: did you label your graphs and include figure captions. **The homework is worth 20 points. 10 points will be given for the overall layout, correctness and neatness of the report, and 10 additional points will be for specific technical things that the TAs will look for in the report itself.**
- **Late reports are subject to a 2 points/day penalty up to five days. They will be no longer accepted afterwards. For example, if your report is three days late and you managed to get 16/20, your final grade will be $16 - 6 = 10$.** Please take into account that you will lose 2% of your overall course grade for each day the report is late. So be careful.

PROBLEM DESCRIPTION: FINDING SUBMARINES

Your goal in this homework is to locate a submarine in the Puget Sound using **noisy acoustic data**. We do not know much about this submarine as it is a new technology that emits an unknown acoustic frequency that you need to detect. Furthermore, the submarine is moving so its location and path need to be determined.

Broad spectrum recording of acoustics data obtained over 24 hours in half-hour increments is available to you. You can download the data from using the Google drive links on Canvas; either of the data files `subdata.npy` for Python users, `subdata.mat` for MATLAB users or `subdata.csv` in text format if previous two formats are insufficient. These files contain a matrix with 49 columns of data corresponding to the measurements of acoustic pressure taken over 24 hours. The measurements themselves are 3D and taken on a uniform grid of size $64 \times 64 \times 64$. The provided notebook will visualize this data for you. *If the 3D plots are slow and you cannot see the dynamic behavior of the data consider downloading the GIF file `subdata.gif` on Canvas. This should help you better understand the information in the data set.*

SOME COMMENTS AND HINTS

Here are some useful comments and facts to guide you along the way.

1. First, observe that you are provided three dimensional dynamic data, that is acoustic pressure measurements in 3D and as a function of time. This makes visualization difficult as the data set is effectively four-dimensional (3D+time). If you would like to see temporal variations then I suggest looking at 2D slices of the data as a function of time. That is to complement the GIF/ provided visualization.
2. In class we only saw/ will see 1D and 2D Fourier transforms but here you may need a higher dimensional Fourier transform. Not much changes in the N-D setting except that you need to use the `fftn` function. `fftshift` remains valid and is still needed.
3. Recall Code Samples (FFT examples) and the discussion of the Gaussian function. We saw a useful fact about noise and Fourier transform that will help you in this assignment and in many applications:

It is known that adding mean zero white noise to a signal (Gaussian noise) is equivalent to adding mean zero white noise (Gaussian noise) to its Fourier series coefficients.

This fact enables one to devise a simple and effective "preliminary" noise filtering technique in situations where multiple measurements are available that are subject to the same noise. This is the case in imaging or acoustics applications like our submarine problem. Since the noise is random and mean zero it should average to zero over **many** samples. Thus, averaging the measurements in the Fourier domain is expected to reduce the noise.

The reduction will improve with an increasing number of aligned measurements, but in the case of our submarine, we only have a few measurements so you would still need to do additional filtering.

TASKS

Below is a list of tasks to complete in this homework and discuss in your report.

1. Through **averaging of the Fourier transform** and visual inspection, determine the frequency signature (center frequency) generated by the submarine.
2. Design and implement a **Filter** to extract this frequency signature in order to denoise the data and determine a more robust path of the submarine. You can also plot the 3D path of the submarine if you would like.
3. Determine and **plot the x, y** coordinates of the submarine during the 24 hour period. This information can be used to deploy a sub-tracking aircraft to keep an eye on your submarine in the future.
4. **Bonus (+2 points):** Implement an alternative technique for noise filtering, substantially different than the above step 2, and visualize and compare the results.