M2 - IPParis - Advanced Experimental Methods in Fluid Mechanics
Acquisition - Signal processing

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Go to : `http://perso.ensta-paristech.fr/~monchaux/index.html`
You will find python scripts and Jupyter notebooks you can fill all along the classes as well as the signal that we will analyse. FIles can be downloaded by right-clicking on them.

1 Gaussian white noise

1.1 Average, standard deviation and probability density function

Open the python script `M2DFE_TEA_Ex1_BBG_STAT.py` you can use directly or to feed a Jupyter notebook to answer the following questions.

Question 1 : Plot the raw time signal in a figure. Change the abscissa axis to zoom in and out on this signal. Describe the signal as you see it at the different scales.

Question 2 : Now, we are going to estimate the average and standard deviations of the signal by using a varying number of data points. Fill the NbPt vector with different increasing values to study, on an example, the influence of the number of points used to estimate these statistical moments. Compare to what has been said during the lecture.

Question 3 : Now, we will estimate the probability density function of this Gaussian white noise. First we explore different representation of the function.

— Set the number successive data points NbPt to 2^{20} and NbBin to 100.
— Run the cell, you will get three different plots of the same probability density function. Each of them allows to appreciate different aspects of the function.
— Comment

Question 4 : Now, we have a look at the influence of the number of bins used.

— Choose successively a given number of data points NbPt to pick from the original signal.
— For each chosen value, fill the vector NbBin with 5 increasing values.
— Run the cell, you will get 5 density probability functions estimated over NbPt points using NbBin bins.
— What is the number of intervals that gives the best estimation of the probability density function?
— Plot this number as a function of NbPt.
— Comment.

1.2 Spectrum and auto-correlation

Question 1 : We will estimate the spectrum (the power spectral density) of the Gaussian white noise. To do so, we use the function `scipy.signal.welch` which takes the 6 following inputs :

— Sig1[1 :NbPoint] : the signal restricted to NbPoint points

— Fs : the sampling frequency of the input signal
— window : the window type
— nperseg : the length of the window used
— Noverlap : the number of overlaping points between two successive windows
— Nfft : the number of points over which the FFT is calculated

Plot the spectrum of the Gaussian white noise using different windo lengths. Describe the results you ontain.
In each case, what is the frequential resolution of the spectrum?
Explain what will help you in the future to choose the arguments of `scipy.signal.welch`.

Question 2 : Calculate and plot the auto-correlation of the Gaussian white noise. perform some zoom in and out tyo analyse what you obtained. Comment.

2 Study of three synthetic signals

Open the script `M2IPP_AEMFM_Ex2_3signals.py` and use it to solve the following questions. Think about saving figures that clearly represent what you have found. Do not forget to write down the set of parameters that allowed you to plot it.

Question 1 : plot the three signals as a function of time. Zoom in and out to guess about their content. Emit hypothesis about their nature. Try to guess their first moments and how will their spectra, probability density functions and auto-correlation will be.

Question 2 : For each signal, plot its spectrum by playing with the plotting parameters using what we found in the previous part to get an estimate that you feel is accurate of the spectrum of the signal considered. Do you have more ideas about the nature of these signals?

Question 3 : For each signal, use only 10^{12} points. Plot its probability density by playing with the plotting parameters using what we found in the previous section to get an estimate that you feel is accurate of the PDF of the signal you are considering. Do you have more ideas about the nature of these signals?

Question 4 : For each signal, use now 10^{20} points (the whole signal).
Plot its probability density by playing with the plotting parameters using what we found in the previous section to get an estimate of the PDF of the signal you think is accurate. Do you have more ideas on the nature of these signals?

Question 5 : For each signal, plot its autocorrelation. Zoom in again to make sure you understand the result you have obtained. Do you have any more ideas about the nature of these signals?

Question 6 : Compare the values of the "optimal" parameters that allowed you to understand the nature of the signals studied.

Question 7 : Draw conclusions about what you will do during your internship when you analyze experimental or digital signals.

3 Real signal analysis

We are going to analyze here various real signals by using the statistical quantities that we have just discovered on the synthetic signals.

3.1 Turbulent jet

We are first interested in the signal of a turbulent jet captured by a hot wire. This one measures the longitudinal velocity component U_x at the jet axis at about 60 diameters after the nozzle exit.

Question 1 : Load the `signaljet` file.

1. Plot the velocity signal as a function of time. Zoom in on different time horizons and centered on different instants.
2. Comment on the stationarity of the signal and its frequency content from these visualizations.
3. Compute the mean ($\overline{U_x}$) and standard deviation ($u_{x_{rms}}$) of the velocity over time intervals of different lengths.
4. Comment on the differences obtained. Is the signal stationary?

Question 2 : Calculate the velocity signal spectrum for the full signal.

1. What is the frequency resolution of this spectrum?
2. Comment the obtained spectrum, in particular its bounds

Question 3 : Calculate the spectrum of the velocity signal for different window lengths (*i.e.* frequency resolutions).

1. Comment the obtained spectra and compare them to the one obtained for the full signal.

Question 4 : Plot the auto-correlation and PDF of the jet signal. Discuss the results obtained. Compare to the synthetic signals from the previous exercise.

3.2 Wake

We are now interested in the signal of a turbulent wake captured by a hot wire. The hot wire measures the longitudinal velocity component U_x at the wake axis at about 10 diameters after the cylinder.

Question 1 : Load the file `signal_cylindre.txt`.

1. Plot the velocity signal as a function of time. Zoom in on different time horizons and centered on different instants.
2. Comment on the stationarity of the signal and its frequency content from these visualizations.
3. Compute the mean ($\overline{U_x}$) and standard deviation ($u_{x_{rms}}$) of the velocity over time intervals of different lengths.
4. Comment on the differences obtained. Is the signal stationary?

Question 2 : Calculate the spectrum of the velocity signal using different window lengths (i.e. frequency resolutions). Calculate the PDF and the auto-correlation of the signal.

1. Comment on the different results obtained.

3.3 Gong signal

We are now interested in the pressure signal produced by a gong forced by a coil-magnet system oscillating sinusoidally at a given frequency f_0.

Question 1 : Load the file `gong_force.wav` using `scipy.io.wavfile.read`. This function also returns the sampling frequency and allows to get the number of bits used for discretisation.

1. Plot the pressure signal as well as the forcing signal against time.
2. Calculate the mean ($overlinep$) and standard deviation (p_{rms}) of the pressure over 1 second intervals.
3. Is the signal stationary?

Question 2 : Calculate the pressure response signal spectrum for the full signal ($K = 1$).

1. By playing with the frequency zoom and the scale (lin or log) of the DSP, comment on the content of the pressure response signal.

Question 3 : Calculate the spectrum of the pressure response signal and that of the forcing at 5 Hz resolution without overlap.

1. What is the associated temporal resolution?
2. Is it possible to increase the time resolution?
3. Study the pressure response. What is happening in the system?
4. Study the forcing. Do we find what we would have expected? If not, suggest an explanation.