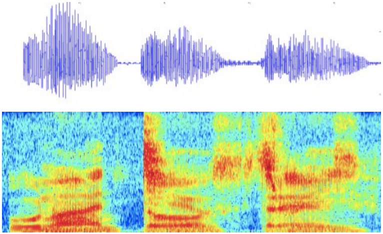
Estimation theory & parametric identification



Signal processing applied to industrial robots model estimation

N. Mechbal, **M. Rébillat**, M. Guskov *[PIMM, ENSAM]*
marc.rebillat@ensam.eu

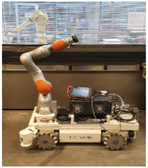
Robotic context

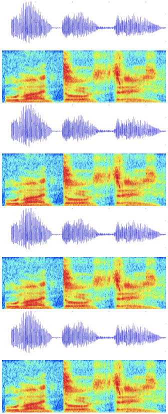
Numerical integration

Numerical differentiation

Model estimation of robotic systems [1, 2, 3]

Robots $\Rightarrow$ **Digital signals** $\Rightarrow$ **Numerical models**





Transfer function

$$H(p) = \frac{Y(p)}{U(p)}$$

State-space model

$$\dot{X} = f(X, U)$$
$$Y = g(X, U)$$

Objective: Estimate a reliable model and its parameters for a robotic system from measurements.

Course objectives

- **With M. Guskov**: Building models of flexible manipulator.
- **With N. Mechbal**: Model parameters estimation.

Within this part of the course

Understanding the signal processing steps of measurements coming from robotic sensors that are necessary to perform model parameters estimation:

1. How do I represent usefully a digital signal?
2. How am I sure to control the data acquisition chain?
3. How do I process reliably acquired signals?
4. Illustration in robotics applications.

Useful references *are made available on the last slide for more details [4, 5, 6, 7, 8, 9, 10, 11].*

Part #3: Signal processing for indutrial robots

How do I apply signal processing tools in practice on industrial robots?

- How to get displacement from acceleration (numerical integration)?
- How to get velocity from position (numerical derivation)?

+ exercises.

Robotic context

Numerical integration

Numerical differentiation

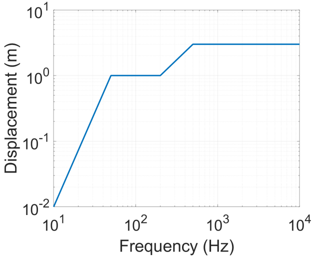
Numerical integration

Why numerical integration is useful in robotics and how to perform it?

- Numerical integration is needed to estimate velocity (m/s) or position (m) from acceleration (m/s^2).
- Numerical integration is equivalent to filtering by a filter $H(f) = \frac{1}{j2\pi f}$.
- Numerical integration thus **amplifies low frequencies**.
- **High pass filtering** is needed to avoid noise amplification before numerical integration.

Issues with low frequencies are expected with numerical integration: high pass filtering highly recommended.

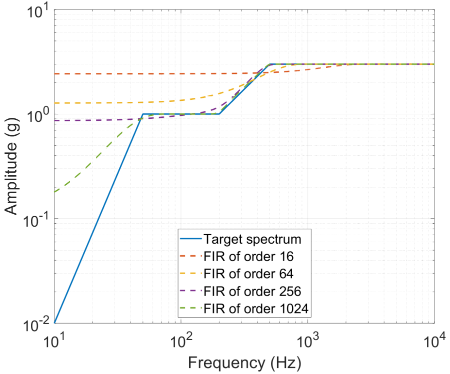
Case study #1: tool acceleration perturbation



Is this case study, we want to:

- study the **effect of a perturbation** induced by a tool at the end of a robotic arm.
- to **generate an acceleration signal** corresponding to this perturbation from the knowledge of its spectrum.
- to **estimate the displacement** caused by this perturbation at the end of the robotic arm.

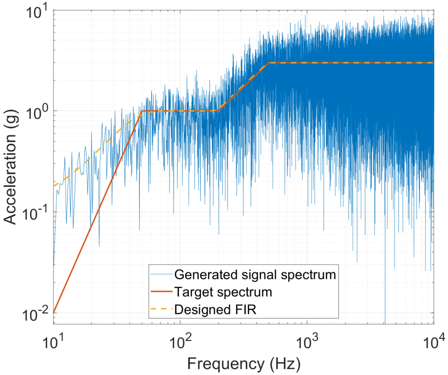
Design a FIR filter fitting the target spectrum



- The idea is to find an appropriate FIR filter using the *fir2* function.
- FIR order greatly influence the obtained results.
- The larger the FIR order, the better the result.
- In low frequencies, there exists still a mismatch.

The target spectrum may only be approximated in practice.

Filtering noise to obtain the perturbation acceleration

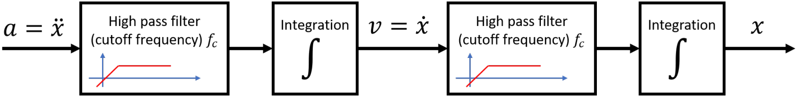


- The idea is to filter a white Gaussian noise (flat spectrum) with the previous FIR filter using the *filt* function.
- The shape of the filtered noise followed in general the target spectrum.
- The filtered signal followed the designed FIR and not exactly the target spectrum.
- In low frequencies, there exists still a mismatch.

The perturbation is overall quite satisfying.

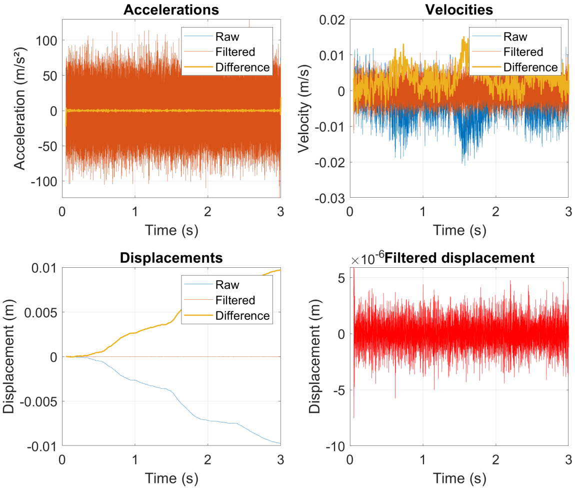
From acceleration to displacement

A tentative noise preventing signal processing chain



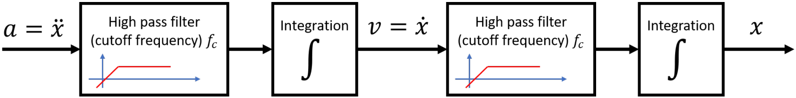
- High pass filtering shall be performed before each integration step.
- IIR digital filters can be designed using the *butter* function and an order 6.
- The cutoff frequency can be selected around 100 Hz as there is no much energy lower than that frequency.
- Signals should be filtered using the *filtfilt* function in order to avoid phase effects.
- Signals can be integrated using the *cumtrapz* function.

Integrate twice the acceleration signal



Filtering can prevent the low frequency drifts in displacement.

Summary regarding numerical integration



- Numerical integration can be dangerous.
- Low frequency noise can be greatly amplified if no precautions are taken.
- It is recommended to high pass filter signals to be integrated before proceeding to integration.
- The cutoff frequency is application dependent and should be selected according to the frequency content of interest.

Be careful !

Robotic context

Numerical integration

Numerical differentiation

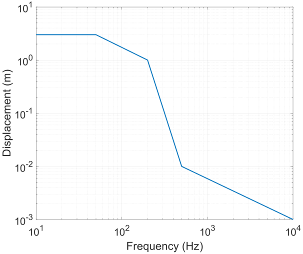
Numerical differentiation

Why numerical differentiation is useful in robotics and how to perform it?

- Numerical differentiation is needed to estimate velocity (m/s) or acceleration (m/s^2) from position (m).
- Numerical differentiation is equivalent to filtering by a filter $H(f) = j2\pi f$.
- Numerical differentiation thus **amplifies high frequencies**.
- **Low pass filtering** is needed to avoid noise amplification before numerical differentiation.

Issues with high frequencies are expected with numerical differentiation: low pass filtering highly recommended.

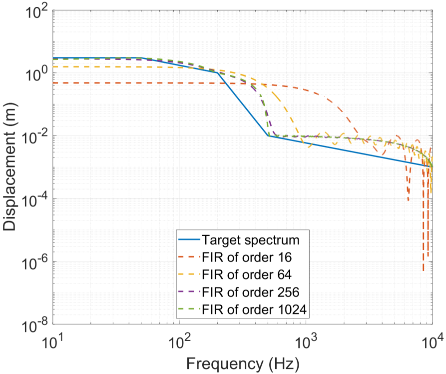
Case study #2: floor induced displacement



Is this case study, we want to:

- study the **effect of a perturbation** induced by a neighbouring robot through the floor at the end of a robotic arm.
- to **generate a floor displacement signal** corresponding to this perturbation from the knowledge of its spectrum.
- to **estimate the acceleration** caused by this perturbation at the end of the robotic arm.

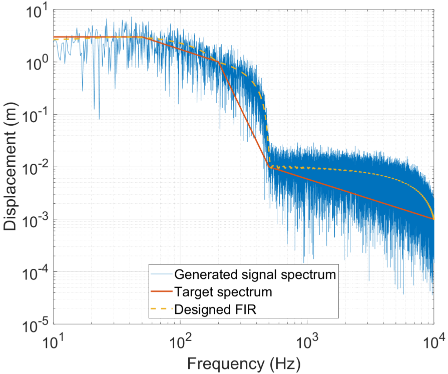
Design a FIR filter fitting the target spectrum



- The idea is to find an appropriate FIR filter using the *fir2* function.
- FIR order greatly influence the obtained results.
- The larger the FIR order, the better the result.

The target spectrum may only be approximated in practice.

Filtering noise to obtain the perturbation acceleration

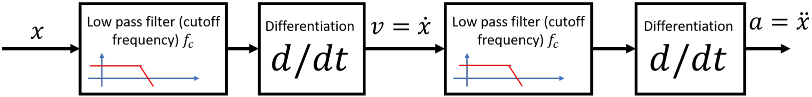


- The idea is to filter a white Gaussian noise (flat spectrum) with the previous FIR filter using the *filt* function.
- The shape of the filtered noise followed in general the target spectrum.
- The filtered signal followed the designed FIR and not exactly the target spectrum.

The perturbation is overall quite satisfying.

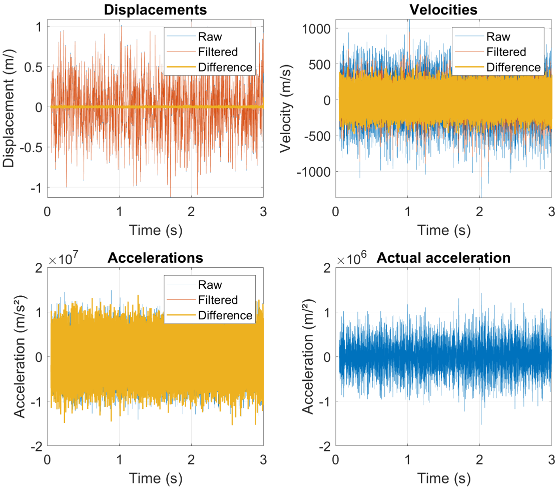
From displacement to acceleration

A tentative noise preventing signal processing chain



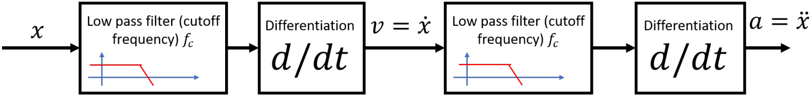
- Low pass filtering shall be performed before each differentiation step.
- IIR digital filters can be designed using the *butter* function and an order 6.
- The cutoff frequency can be selected around 500 Hz as there is no much energy lower than that frequency.
- Signals should be filtered using the *filtfilt* function in order to avoid phase effects.
- Signals can be differentiated using the *diff* function.

Differentiate twice the displacement signal



Filtering can prevent the high frequencies amplifications in acceleration.

Summary regarding numerical integration



- Numerical differentiation can be dangerous.
- High frequency noise can be greatly amplified if not precautions are taken.
- It is recommended to low pass filter signals to be differentiated before proceeding to differentiation.
- The cutoff frequency is application dependent and should be selected according to the frequency content of interest.

Again, be careful !

Course objectives

- **With M. Guskov**: Building models of flexible manipulator.
- **With N. Mechbal**: Model parameters estimation.

Within this part of the course

Understanding the signal processing steps of measurements coming from robotic sensors that are necessary to perform model parameters estimation:

1. How do I represent usefully a digital signal?
2. How am I sure to control the data acquisition chain?
3. How do I process reliably acquired signals?
4. Illustration in robotics applications.

Useful references *are made available on the last slide for more details [4, 5, 6, 7, 8, 9, 10, 11].*

Bibliography

[1] W. Khalil and E. Dombre. *Modeling, identification and control of robots*. Butterworth-Heinemann, 2004.

[2] J. Wu, J.and Wang and Z. You. An overview of dynamic parameter identification of robots. *Robotics and computer-integrated manufacturing*, 26(5):414–419, 2010.

[3] K. R. Kozlowski. *Modelling and identification in robotics*. Springer Science & Business Media, 2012.

[4] A. V. Oppenheim. *Discrete-time signal processing*. Pearson Education India, 1999.

[5] Y. Meyer and P. Flandrin. Time-frequency/time-scale analysis. *Wavelet Analysis and its applications*, 1999.

[6] S. Mallat. *A wavelet tour of signal processing*. Elsevier, 1999.

[7] W. M. Hartmann. *Signals, sound, and sensation*. Springer Science & Business Media, 2004.

[8] S. K. Mitra and Y. Kuo. *Digital signal processing: a computer-based approach*, volume 2. McGraw-Hill New York, 2006.

[9] K. Shin and J. Hammond. *Fundamentals of signal processing for sound and vibration engineers*. John Wiley & Sons, 2008.

[10] D. Havelock, S. Kuwano, and M. Vorländer. *Handbook of signal processing in acoustics*. Springer Science & Business Media, 2008.

[11] M. Weeks. *Digital signal processing using MATLAB & wavelets*. Jones & Bartlett Publishers, 2010.