Data preparation for System Identification

Carpentry

Preparation and prejudice

The sugar mill is available for experiment

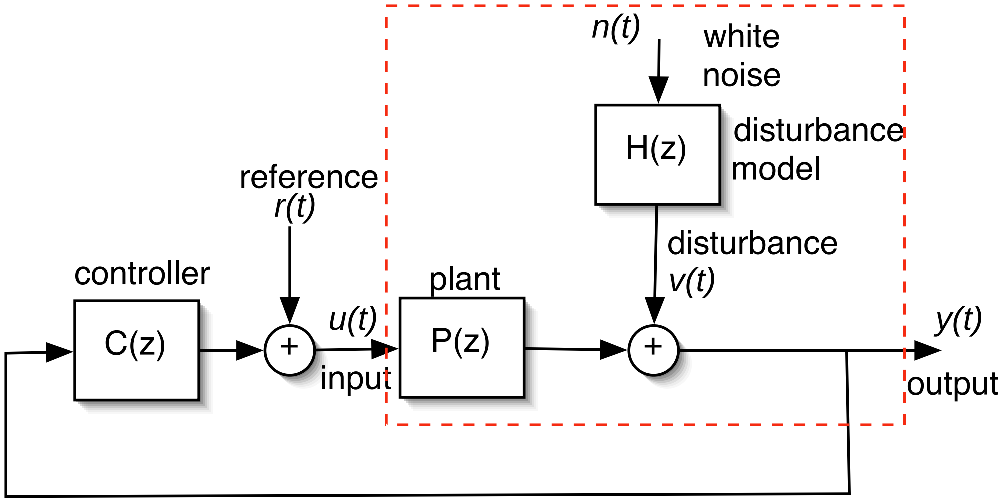
We need to get some prejudicial decision made before we can start delving into System Identification via matlab toolbox

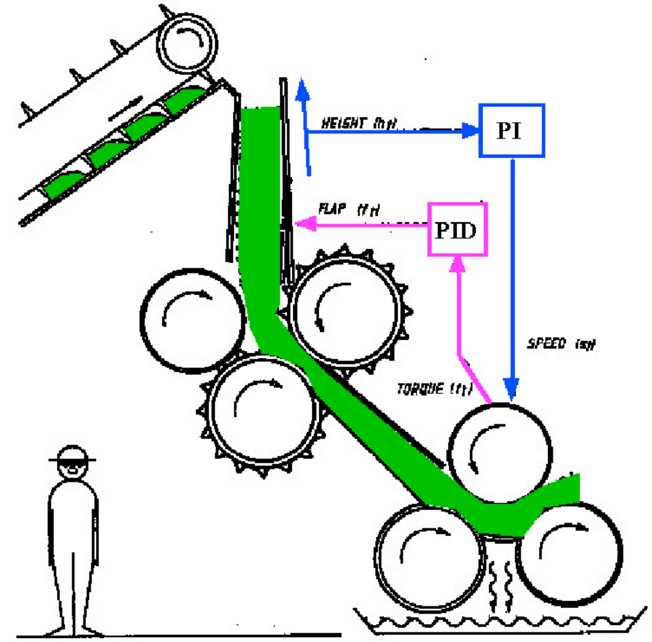
- Almost all our work goes into this section of modeling
  - In this way System Identification is more like painting

Variables needing specification

- Model structure - parametrization of $\hat{P}(z,\theta)$ and $\hat{H}(z,\theta)$
- Experiment design - reference input selection
- Data selection - not all data is suited to linear modeling
- Data filtering - to reflect our control objective

Formulations





$$\lim_{N\to\infty}\frac{1}{N}\sum_{k=1}^{N}\left\{L(z)[y_k-\hat{y}_{k|k-1}]\right\}^2 =$$

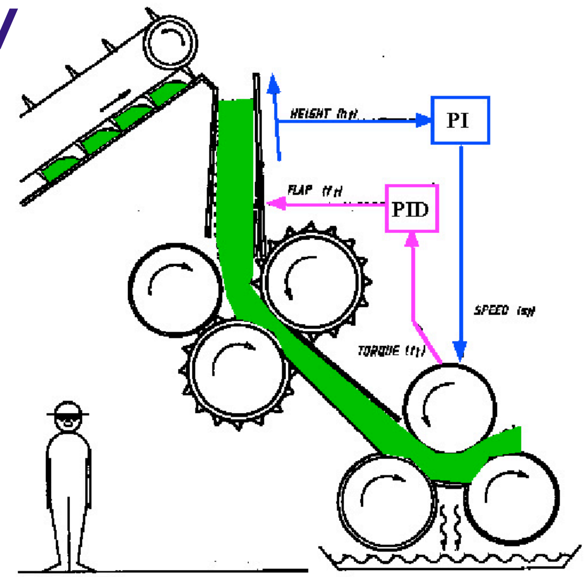
$$\frac{1}{2\pi}\int_{-\pi}^{\pi}\left\{\frac{\left|P(e^{j\omega})-\hat{P}(e^{j\omega},\theta)\right|^2}{\left|1+P(e^{j\omega})C(e^{j\omega})\right|^2}\left|C(e^{j\omega})\right|^2\Phi_r(\omega)\right.$$

$$\left.+\frac{\left|1+\hat{P}(e^{j\omega},\theta)C(e^{j\omega})\right|^2}{\left|1+P(e^{j\omega})C(e^{j\omega})\right|^2}\left|H(e^{j\omega})\right|^2\right\}\frac{\left|L(e^{j\omega})\right|^2}{\left|\hat{H}(e^{j\omega},\theta)\right|^2}\,d\omega$$

Model structure selection

- We really insist on as simple a model as is possible
  - Parsimony plus - we need to use the model for control design
  - Data is non-stationary and non-linear
    - We might have trouble finding enough useful data
      - Fewer parameters require fewer data to identify reliably
- We seek to have the disturbance model and plant model separately parametrized
  - Allows us better control of bias in the plant estimation using closed-loop data
- We cannot conduct open-loop experiments
  - The cookbook formulae of selstruc are not necessarily applicable

The things we know



A step increase in speed leads to
- A ramp decrease of the chute height
- A step decrease of torque

A step increase in flap leads to
- A ramp decrease in chute height
- A step decrease in torque

There are integrators in *P(z)* between speed and chute height and between flap and chute height

A change of cane variety leads to
- Ramp changes in chute height
- Step changes in torque

There is an integrator in the chute channel of *H(z)* none in torque

Gedankenexperiments

$$\begin{pmatrix} t_t \\ h_t \end{pmatrix} = \begin{pmatrix} -A(z) & -C(z) \\ \frac{1}{1-z^{-1}}B(z) & \frac{-1}{1-z^{-1}}D(z) \end{pmatrix} \begin{pmatrix} f_t \\ s_t \end{pmatrix} + \begin{pmatrix} E(z) \\ \frac{-1}{1-z^{-1}}F(z) \end{pmatrix} n_t$$

Physical consideration of model form

- Corroborated by the existing PI and PID control loops
  - Correctly typed system

Information about the eventual controller requirements

- Step and ramp disturbance rejection function
  - Low frequency emphasis
  - Coupled loops
- Bandwidth extension from PI/PID controller
- Feasible gains understood
- Open-loop stable with anti-windup properties

Experiment design - reference selection

$$\lim_{N\to\infty}\frac{1}{N}\sum_{k=1}^{N}\left\{L(z)[y_k-\hat{y}_{k|k-1}]\right\}^2 =$$

$$\frac{1}{2\pi}\int_{-\pi}^{\pi}\left\{\frac{\left|P(e^{j\omega})-\hat{P}(e^{j\omega},\theta)\right|^2}{\left|1+P(e^{j\omega})C(e^{j\omega})\right|^2}\left|C(e^{j\omega})\right|^2\Phi_r(\omega)\right.$$

$$\left.+\frac{\left|1+\hat{P}(e^{j\omega},\theta)C(e^{j\omega})\right|^2}{\left|1+P(e^{j\omega})C(e^{j\omega})\right|^2}\left|H(e^{j\omega})\right|^2\right\}\frac{\left|L(e^{j\omega})\right|^2}{\left|\hat{H}(e^{j\omega},\theta)\right|^2}\,d\omega$$

Without reference

$$\hat{P}(z,\theta)\approx -C^{-1}(z)$$

Reference should swap disturbance

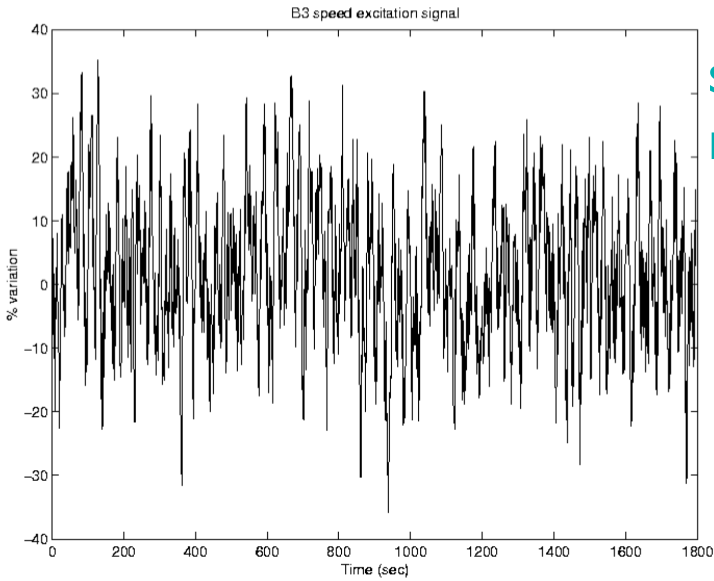
Reference should expose *P(z)* within bandwidth of ultimate controller

Choose *r(t)* with following objective

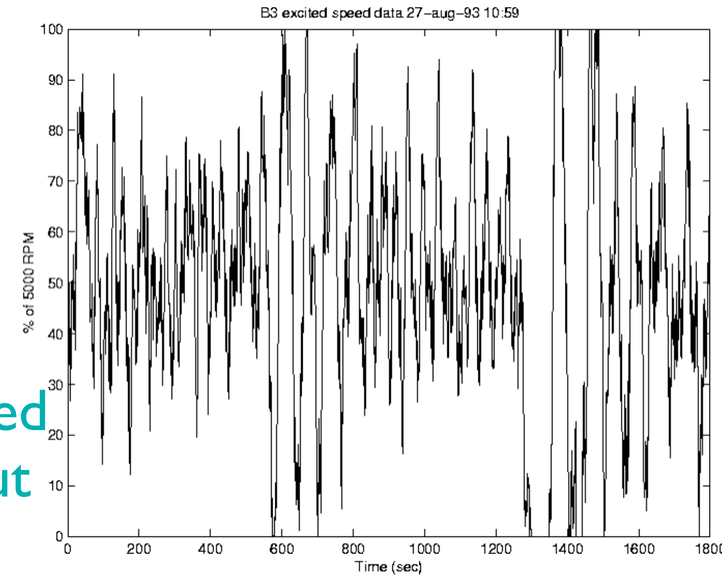
- very strong low frequency content
- frequency content out to about 0.3Hz
- avoid saturation in inputs and outputs
- statistically independent from the disturbance

Reference adds to existing closed-loop feedback control signal

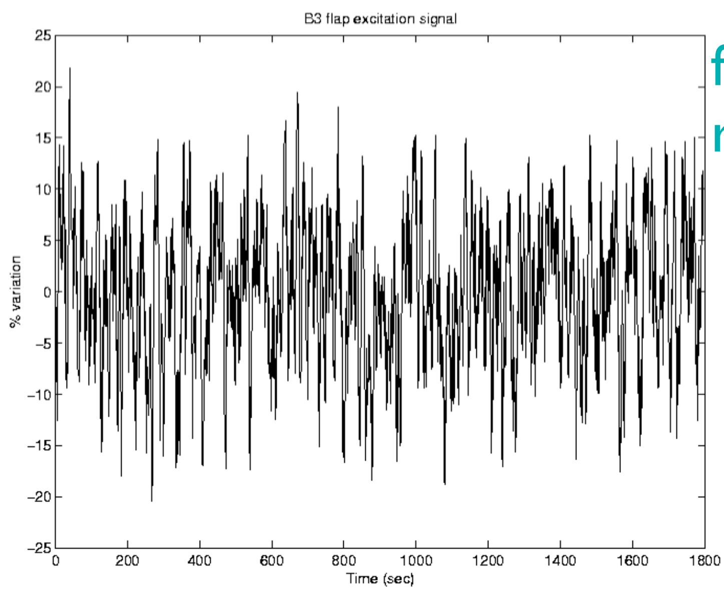
Reference excitations



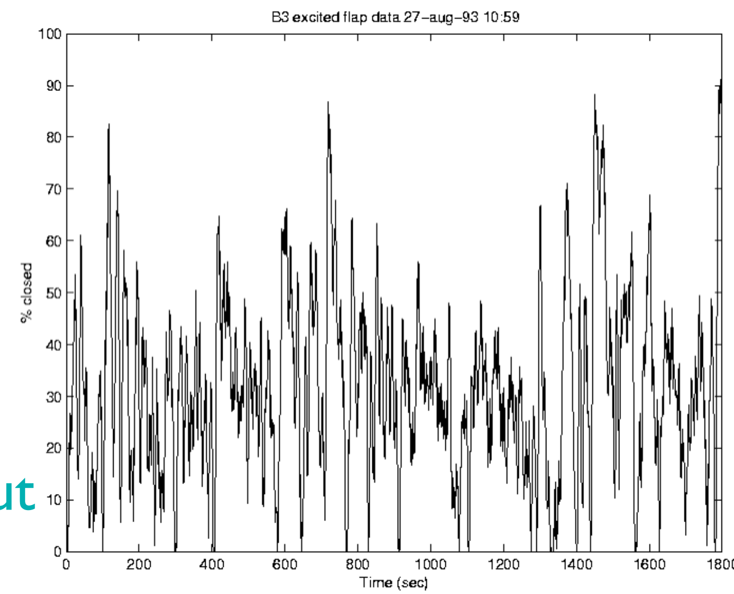
speed reference



speed input

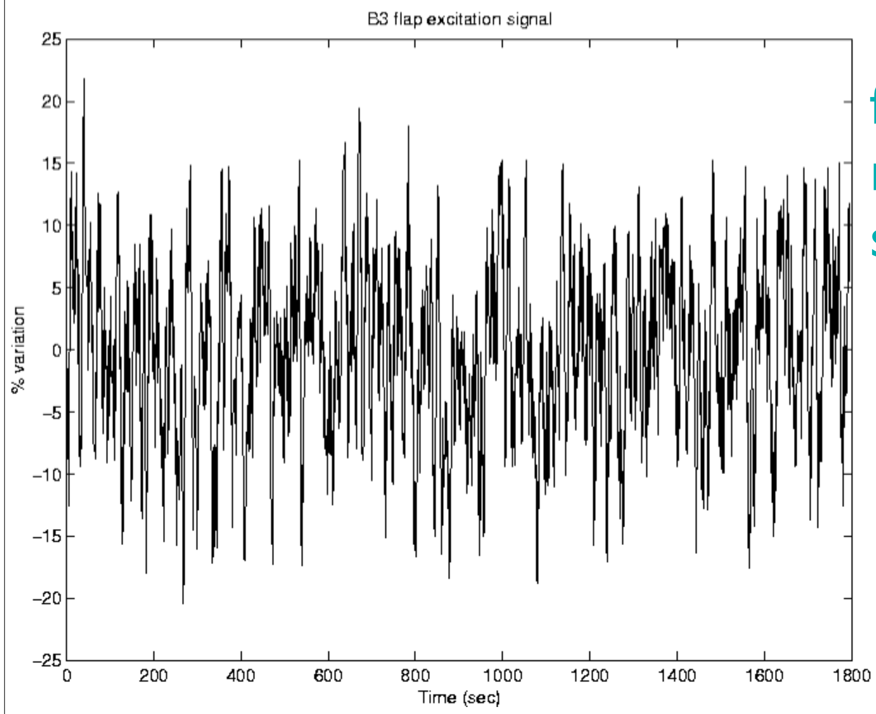


flap reference



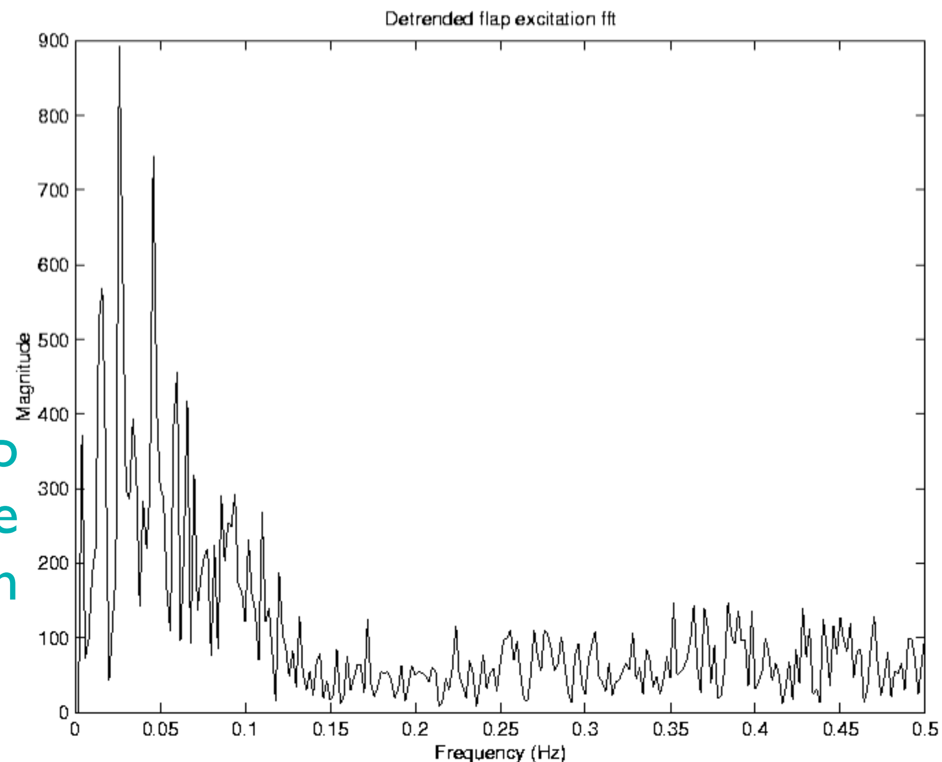
flap input

Excitation spectrum

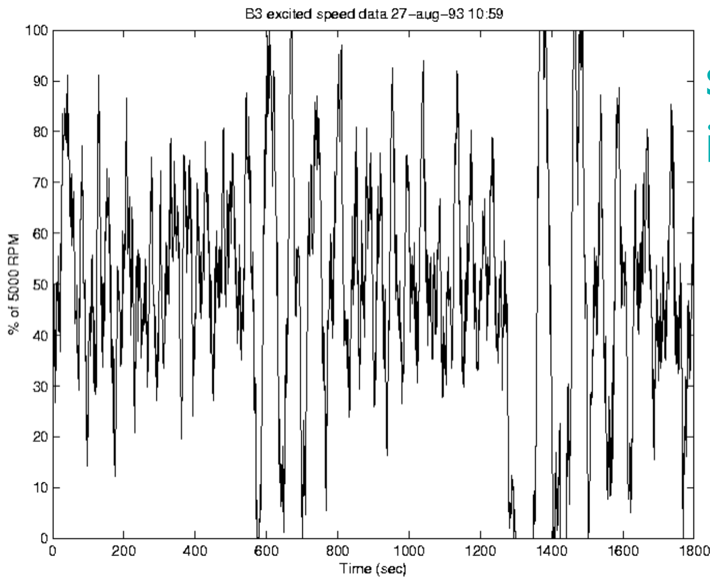


flap reference signal

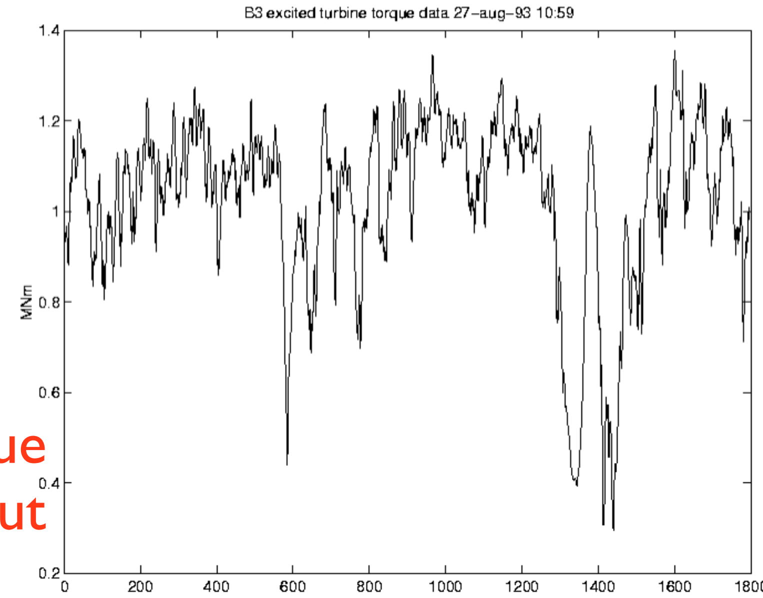
flap reference spectrum



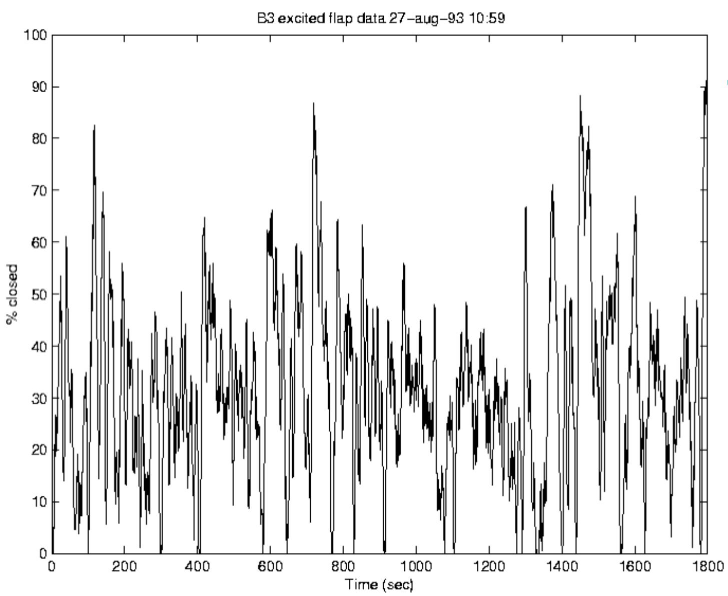
Meet the data - PI/PID control operating



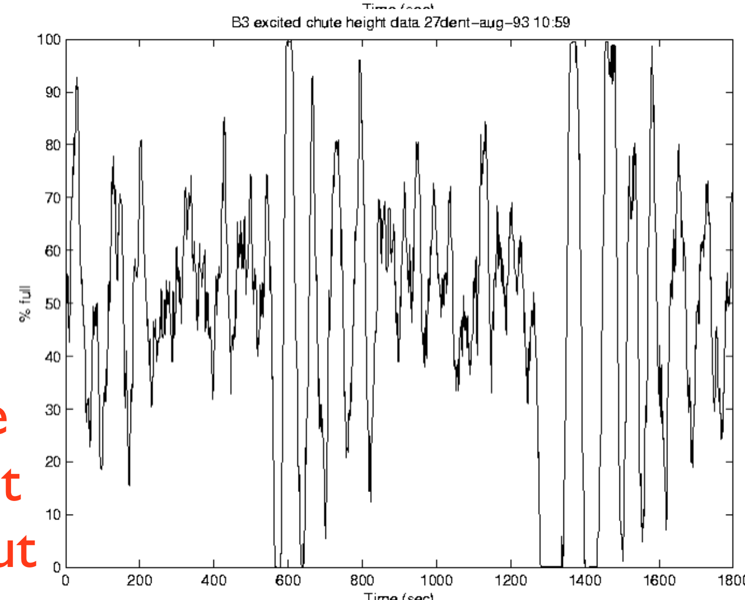
speed
input



torque
output

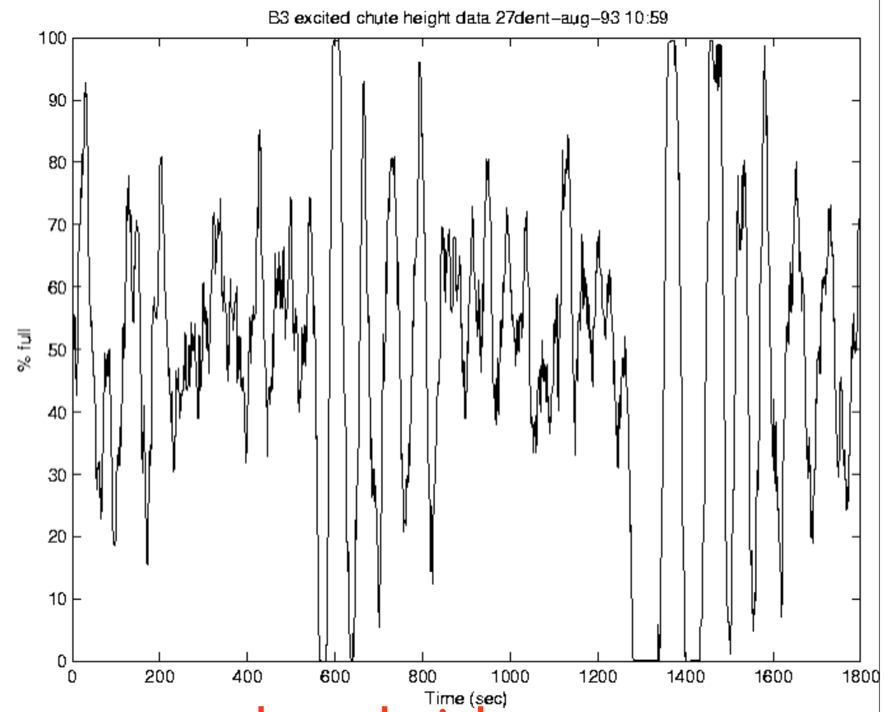


flap
input



chute
height
output

Data selection



chute height output

Not all data suited to linear modeling

Saturation

Instability

Disturbance dominates reference

Clearly we need better control

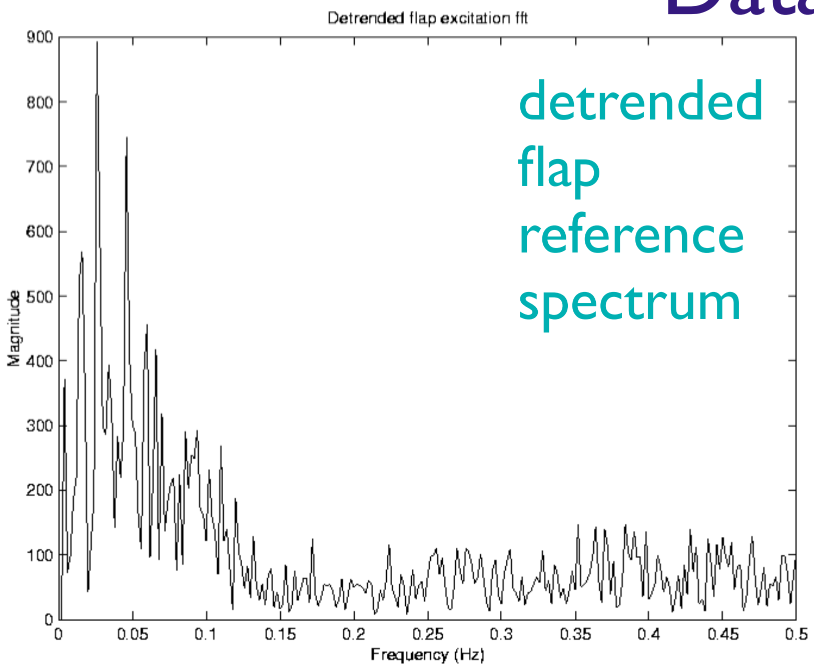
Select two data sets

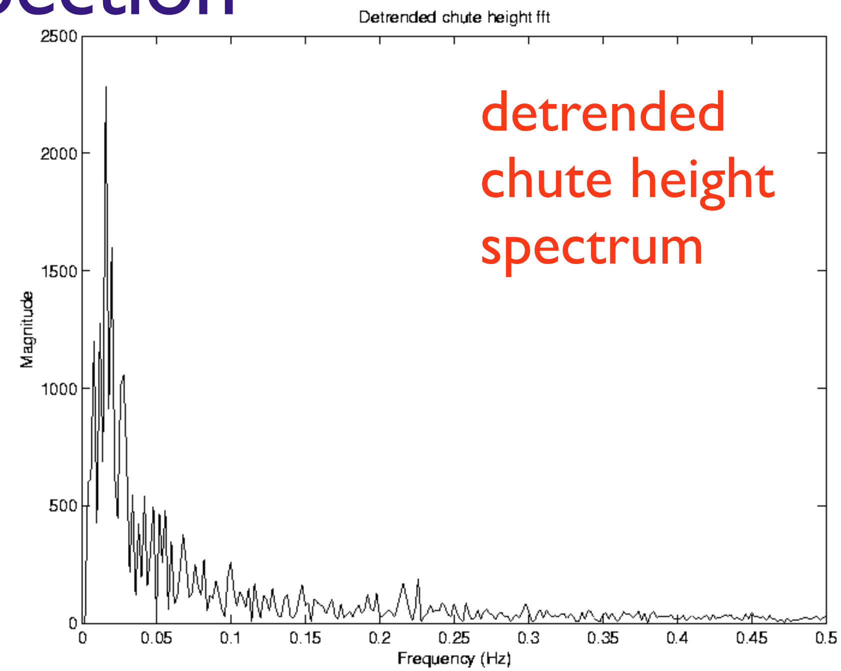
One for model fitting - evaluation set 51:550

One for model validation - validation set 851:1250

Note: not all data is equally valuable!

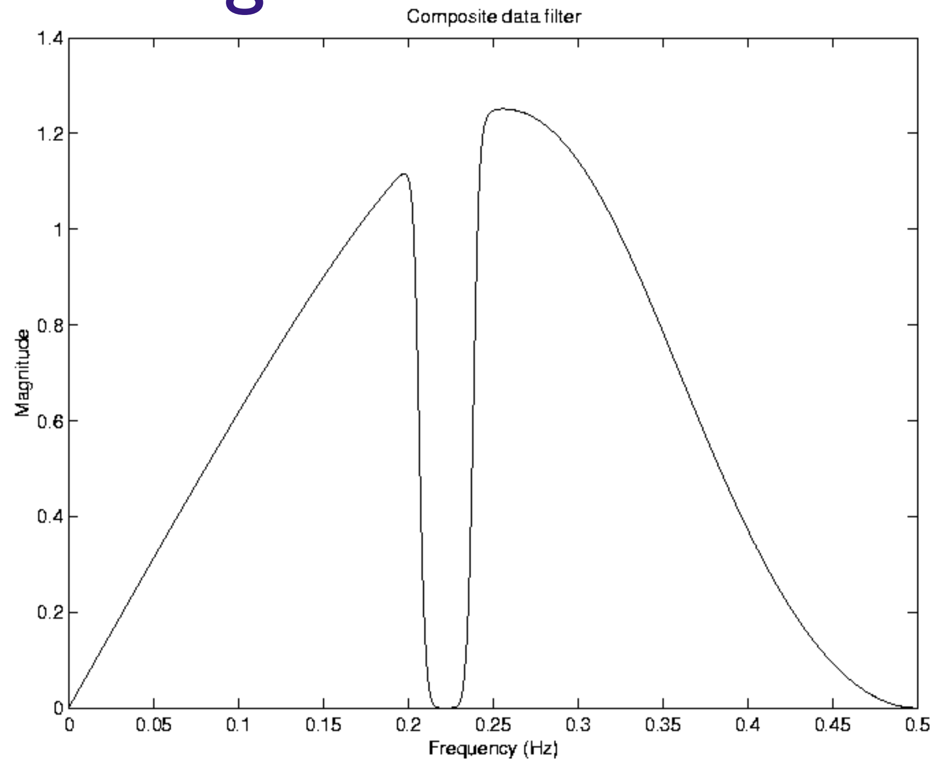
Data inspection





- Data is detrended
  - Constant (DC) term is removed
    - Permits analysis of other signal content
      - We already have a model of the system at DC
- There is a curious bump in chute height spectrum around 0.23Hz
  - This is the inter-mill carrier time-passing frequency

Data filtering



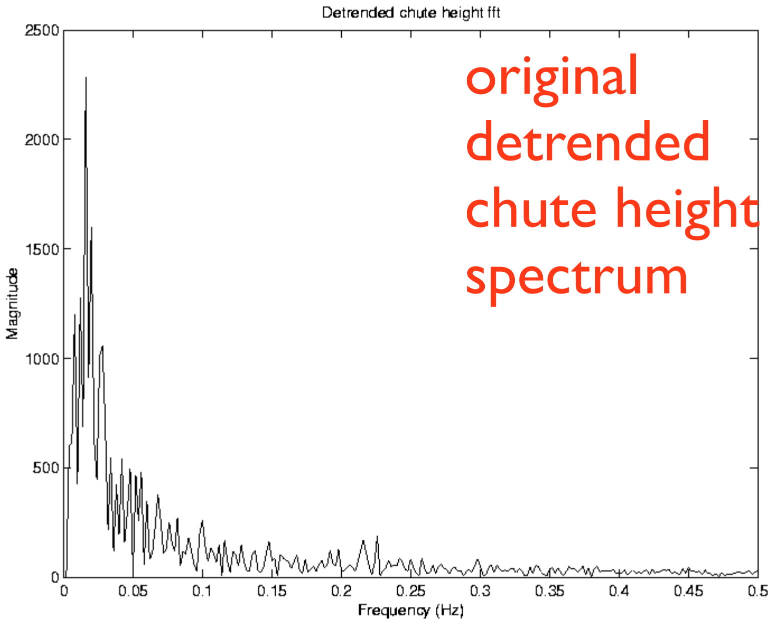
All data are filtered the same

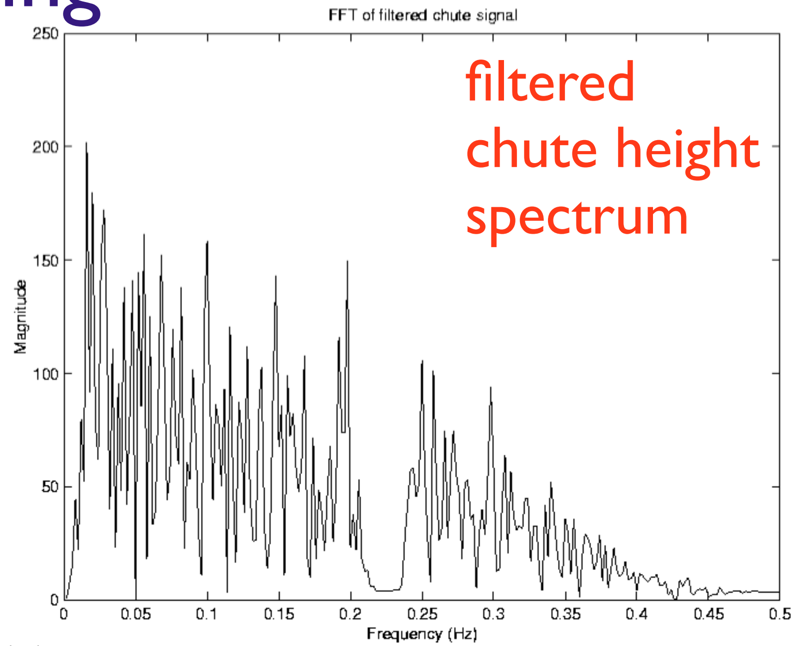
Three components

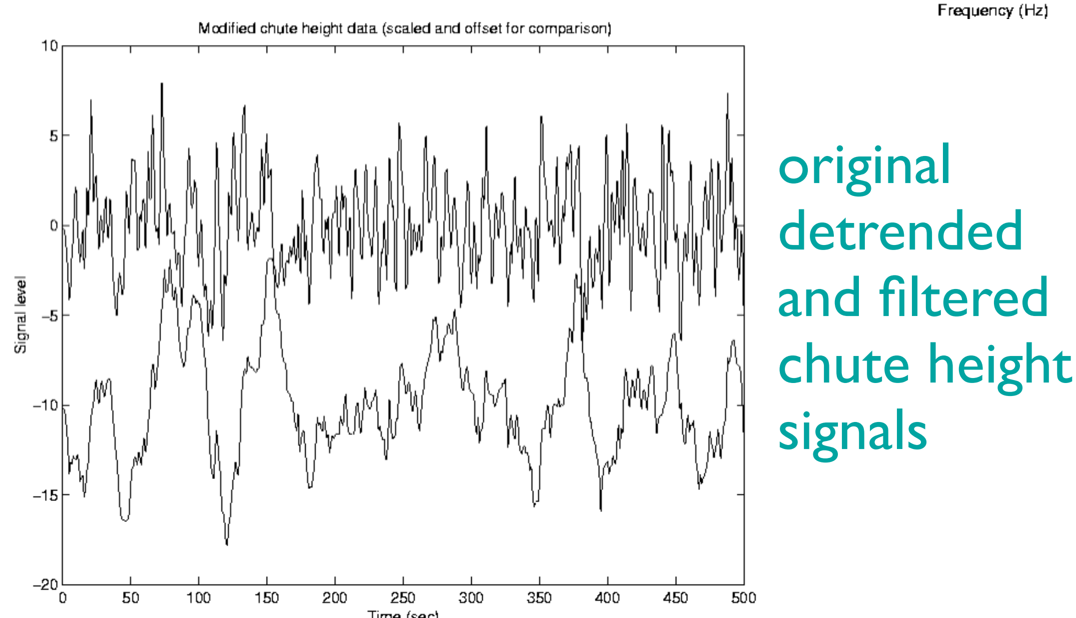
- Differencer $1 - z^{-1}$ eliminates DC terms and cancels integrators from model estimation
- Low-pass filter to remove high-frequency noise
- Narrow-band notch filter to remove tine signal

Filtering is the same as a priori specification of part of $\hat{H}(z, \theta)$

Data filtering







Conclusion

Prejudice

We need to use all our prejudices to cajole the system identification to yield a model suited to our purpose of control design

We do not know precisely the final control law

- But we have some pretty good ideas about what is should be
  - Let us try to pre-ordain the outcome
    - Make the model fit well where the controller needs it