Identification for Control

A rather extreme example in helicopter vibration control
Vibration from rotors leads to pilot fatigue

Passive vibration damping system needs active control

Feedback from accelerometers near pilot to active dampers

Hydraulic system coupled with spring plates

Under-actuated but expect improvement over passive control
System information a priori

Range of vibration frequencies is very limited 17Hz ±5%

An under-damped mode lies around 40Hz

System is stable in open-loop

No control produces no craziness

The vibration frequency changes only slightly in flight

The airframe dynamics change with configuration and load

Look for a stable model with a simple parametrization

Control design will use open-loop stability - low gain solution

Adaptive solution for changing dynamics and frequency

Slow changes
The putative control solution

\[ y(t) = [1 + PCA]^{-1} v(t) \]

Performance: need \( 1 + PCA \) very large at vibration frequency 17Hz
Need \( CA \) small near the unmodeled resonance at 40Hz
Robust stability given by \( CA \) almost zero
Look for a perturbation on \( CA=0 \)
\( A(z) \) an oscillator
\( C(z) \) a phase compensator
Stability tied to the phase of \( C(z) \) at the oscillation frequency
Model requirements

Low-order simple model

- High frequency detail managed by the controller not modeling
  - Parametric model is good foe adaptation
  - Want few parameters to estimate
  - Data is very sinusoidal - not informative

The model should be stable just like the real plant

- A low-gain control strategy is adopted
  - Matches the robust stability approach

The fit in the neighborhood of 15Hz to 20Hz is most important

- Actuation incapable of addressing other modes
  - Accommodation of model mismatch by the controller
Non-parametric model data
DFT magnitudes of 15Hz excited output
Cleaning the data - filtering

\[ \hat{P}(e^{j\omega_i}) = \frac{\sum_{k=1}^{1000} y_{i,k} \exp\left(j\omega_i k / T\right)}{\sum_{k=1}^{1000} u_{i,k} \exp\left(j\omega_i k / T\right)} \]

Sinusoidal experimental data collected at 21 frequencies

Input sinusoid contains some small harmonic distortion

Accelerometer signal contains very significant harmonic distortion

Pass both through a very narrow-band-pass filter

This is achieved with the above computations

This is akin to the discrete Fourier transform

Divide the the results to get the frequency response values

21 complex frequency response estimates
Estimated frequency response
Parametric model development

Start with 21 frequency response values centered around 17Hz

Fit a stable low-order model to these values

Direct frequency-domain fit

Difficult to guarantee stability

We actually want a weighted fit to emphasize 17Hz

Use the estimated frequency response values to cook up some fake data with the correct frequency distribution.

Fit the model using this data record and Output Error model structure

Guaranteed stable
Parametric model fit
Model-based control design

Frequency-weighted Linear Quadratic Gaussian Control for disturbance rejection
Controller robustness check
Conclusion

The problem specification and our prejudice about the solution have colored the whole modeling and control design

Modeling has reflected the robust control requirements

- Experiment design
  - Data concentrated where phase accuracy needed
  - Sinusoidal excitation avoided rate limiters

- Data preparation before modeling
  - Harmonic distortion needed to be removed via filtering
  - Parametric model has low order and is stable
    - Heavy frequency weighting in model fit stage

Control design

- Frequency weighted against model mismatch at HF
- Don’t care at LF