ECE 2695: Adaptive Control (3 Credits, Fall 2008)

Lecture 11: Practical Aspects of Adaptive Control

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Outline

- Reading assignment
- Review of last lecture
- Sampling and pre- and postfiltering
- Estimator implementation
- Interaction of estimation and control

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Reading assignment

- T. M. Mitchell, The discipline of machine learning, Report No. CMU-ML-06-108, School of Computer Science, Carnegie Mellon University, 2006.
- K. Doya, What are the computations of the cerebellum, the basal ganglia and the cerebral cortex? Neural networks, vol. 12, pp. 961-974, 1999.

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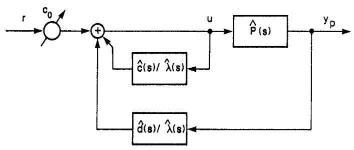
Review of last lecture

- Controller design: output design



Degree? Degree?

$$u = c_0 r + \frac{\hat{c}(s)}{\hat{\lambda}(s)}(u) + \frac{\hat{d}(s)}{\hat{\lambda}(s)}(y_p)$$

Degree? Degree?

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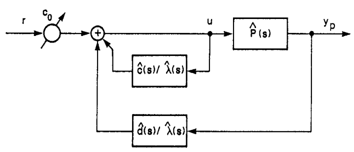
Review of last lecture

- Controller design: output design



Theorem: There exist unique $c_0^*, \hat{c}^*(s), \hat{d}^*(s)$ such that the transfer function from $r \to y_p$ is $\hat{M}(s)$.

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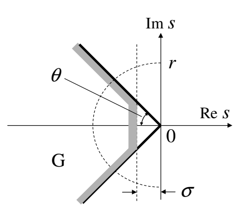
Review of last lecture

- Controller design: output design
- Controller design: state feedback



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Review of last lecture

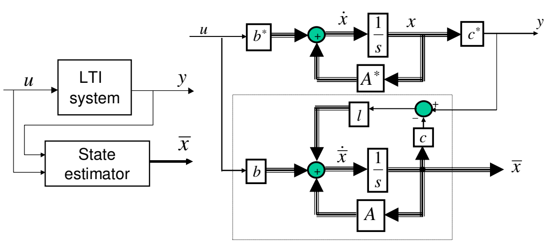
- Controller design: output design
- Controller design: state feedback

Theorem: If $(A,\ b)$ is controllable, then by state feedback $u = r - kx$, where k is a 1 by n real constant vector, the eigenvalues of $A - bk$ can arbitrarily be assigned provided that complex conjugate eigenvalues are assigned in pairs.

Theorem (multivariable case)**:** All eigenvalues of $A - BK$ can be assigned arbitrarily (provided complex conjugate eigenvalues are assigned in pairs) by selecting a real constant matrix K if and only if $(A,\ B)$ is controllable.

Review of last lecture

- Controller design: output design
- Controller design: state feedback



Sampling and pre- and postfiltering

- Choice of sampling rate

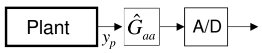
$$\omega_0 h \approx 0.2 \sim 0.6$$

- ω_0 is the natural frequency of the dominating poles of the closed-loop system
- h is the sampling interval
- Sampling frequency is $\omega_s = 2\pi / h$

Question: What is the Nyquist frequency ω_N ?

Sampling and pre- and postfiltering

- Choice of sampling rate
- Prefiltering
  - In all digital systems it is important that signals are filtered before they are sampled



  - All components of the signals with frequencies above the Nyquist frequency should be eliminated (why?)

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Sampling and pre- and postfiltering

- Choice of sampling rate
- Prefiltering
  - In all digital systems it is important that signals are filtered before they are sampled
  - All components of the signals with frequencies above the Nyquist frequency should be eliminated
  - Aliasing: A signal component with frequencies $\omega > \omega_N$ will appear as low-frequency components with the frequency

$$\omega_a = \left|\left((\omega + \omega_N) \text{ mod } \omega_s\right) - \omega_N\right|$$

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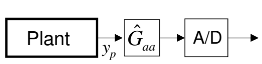
Sampling and pre- and postfiltering

- Choice of sampling rate
- Prefiltering
  - In all digital systems it is important that signals are filtered before they are sampled
  - All components of the signals with frequencies above the Nyquist frequency should be eliminated
  - Aliasing
  - Prefilters introduced before a sampler are called anti-aliasing filters



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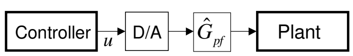
Sampling and pre- and postfiltering

- Choice of sampling rate
- Prefiltering
  - In all digital systems it is important that signals are filtered before they are sampled
  - All components of the signals with frequencies above the Nyquist frequency should be eliminated
  - Aliasing
  - Prefilters introduced before a sampler are called anti-aliasing filters
  - Commonly used anti-aliasing filters: Butterworth, ITAE (integral time absolute error), and Bessel filters; they consist of one or several cascaded filters of the form

$$\hat{G}_f(s) = \frac{\omega^2}{s^2 + 2\varsigma\omega s + \omega^2}$$

Sampling and pre- and postfiltering

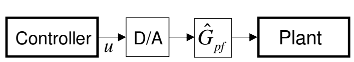
- Choice of sampling rate
- Prefiltering
- Postfiltering



  - The output of a D/A converter is a piecewise constant signal
  - The control signal fed to the actuator is a piecewise constant signal that changes stepwise at the sampling instants (why this may create problem?)

Sampling and pre- and postfiltering

- Choice of sampling rate
- Prefiltering
- Postfiltering



  - The output of a D/A converter is a piecewise constant signal
  - The control signal fed to the actuator is a piecewise constant signal that changes stepwise at the sampling instants
  - For some systems, such as hydraulic servos for flight control and other systems with poorly damped oscillatory modes, the steps may excite these modes
  - In such cases, it is advantageous to use a filter that smoothes the signals from the D/A converter; such a filter is called a postsampling filter

Estimator implementation

- Model structure
  - One reason for the success of automatic control is that good control can often be based on relatively simple dynamic models
  - In adaptive control it is attempted to fit a simple linear model on-line and to adjust the parameters
  - The difficulty in on-line parameter estimation increases significantly with the number of parameters in the model

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Estimator implementation

- Model structure
  - One reason for the success of automatic control is that good control can often be based on relatively simple dynamic models
  - In adaptive control it is attempted to fit a simple linear model on-line and to adjust the parameters
  - The difficulty in on-line parameter estimation increases significantly with the number of parameters in the model
  - Therefore, it is useful to try to reduce the number of unknown parameters as much as possible

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Estimator implementation

- Model structure
- Data filters and excitation
  - Inputs and outputs should be filtered by a band pass filter before these signals are sent to the parameter estimator
  - These filters will remove low-frequency disturbances and high frequency disturbances

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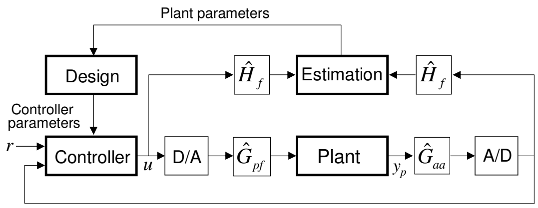

Estimator implementation

- Model structure
- Data filters and excitation
  - Inputs and outputs should be filtered by a band pass filter before these signals are sent to the parameter estimator
  - These filters will remove low-frequency disturbances and high frequency disturbances
  - It is necessary for the input signal to be persistently exciting of sufficiently high order to estimate parameters reliably
  - Considering that we are fitting low-order models to high-order systems, it is also necessary that persistency of excitation be achieved with signals in a frequency band where model accuracy is required

Estimator implementation

- Model structure
- Data filters and excitation
- Parameter tracking
  - It is necessary to discount old data (why?)

Estimator implementation

- Model structure
- Data filters and excitation
- Parameter tracking
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  - When parameters are changing, it can be very misleading to use a long data record, since the parameters may not be the same

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Estimator implementation

- Model structure
- Data filters and excitation
- Parameter tracking
  - It is necessary to discount old data
  - When parameters are changing, it can be very misleading to use a long data record, since the parameters may not be the same
  - Exponential forgetting
  - Directional forgetting

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Interaction of estimation and control

- Computational delay
  - It is important to have as short a computational delay as possible

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Interaction of estimation and control

- Computational delay
- Integral action
  - Practically all controllers need integral action to ensure that calibration errors and load disturbances do not give steady-state errors (why?)

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Interaction of estimation and control

- Computational delay
- Integral action
- Compatibility for identification and control
  - So far, we have treated identification and control as two different tasks
  - It is desirable to formulate the adaptive control problem in such a way that the goals for control and identification are compatible

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References

- K. J. Astrom and B. Wittenmark, Adaptive Control, 2nd Edition, Addison-Wesley, 1995.
- C.-T. Chen. Linear System Theory and Design, 3rd Edition, Oxford University Press, 1999.
- S. Sastry and M. Bodson, Adaptive Control: Stability, Convergence, and Robustness, Prentice-Hall, 1989.

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