Follow-On Courses

NDSU ECE 463/663

Lecture #35

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Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

What's Next?

Once you have a background in Mondern Control, the following courses are open to you:

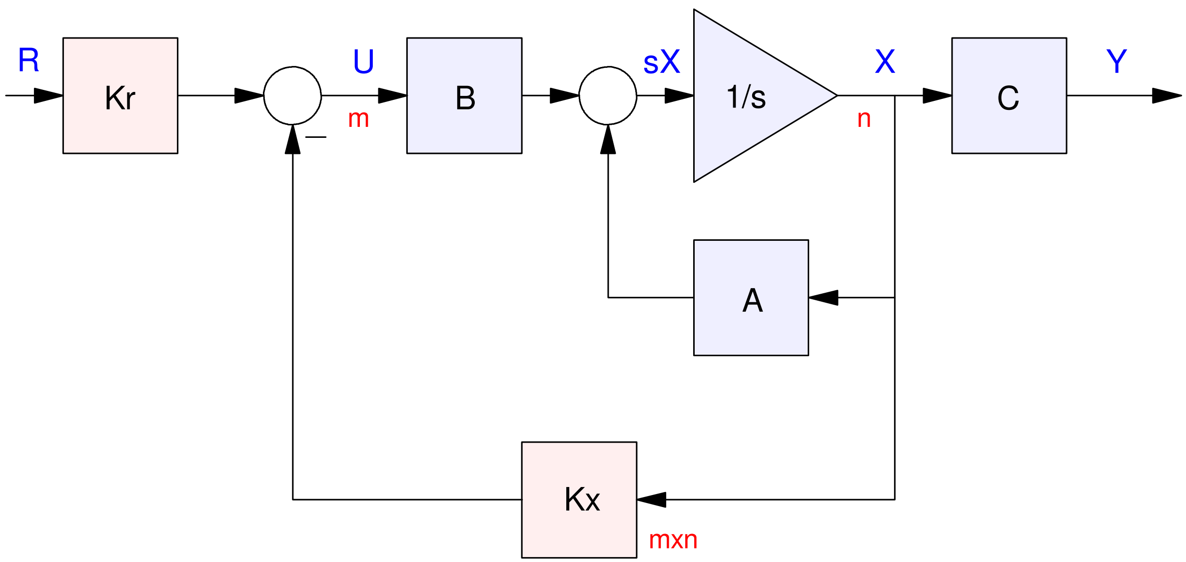
- Multivariable Control
- Nonlinear Control
- Robust Control
- Adaptive Control
- Self-Tuning Regulators

Multivariable Control

Problem: With LQR techniques and multiple inputs, you end up with a full-rank matrix Kx

- Each input requires knowledge of each sensor

$$K_x = \begin{bmatrix} a & b & c & d \\ e & f & g & h \end{bmatrix}$$



How to you constrain Kx so that some terms are zero?

- Only certain sensors are used by each input?

$$K_x = \begin{bmatrix} a & b & 0 & 0 \\ 0 & 0 & c & d \end{bmatrix}$$

Optimal result is the solution to the algebraic ricatti equation

- i.e. it is a solution to the Euler LaGrange equation
- No closed-form solution exists
- Have to solve using numerical methods

Nonlinear Control

LQR techniques apply to linear systems

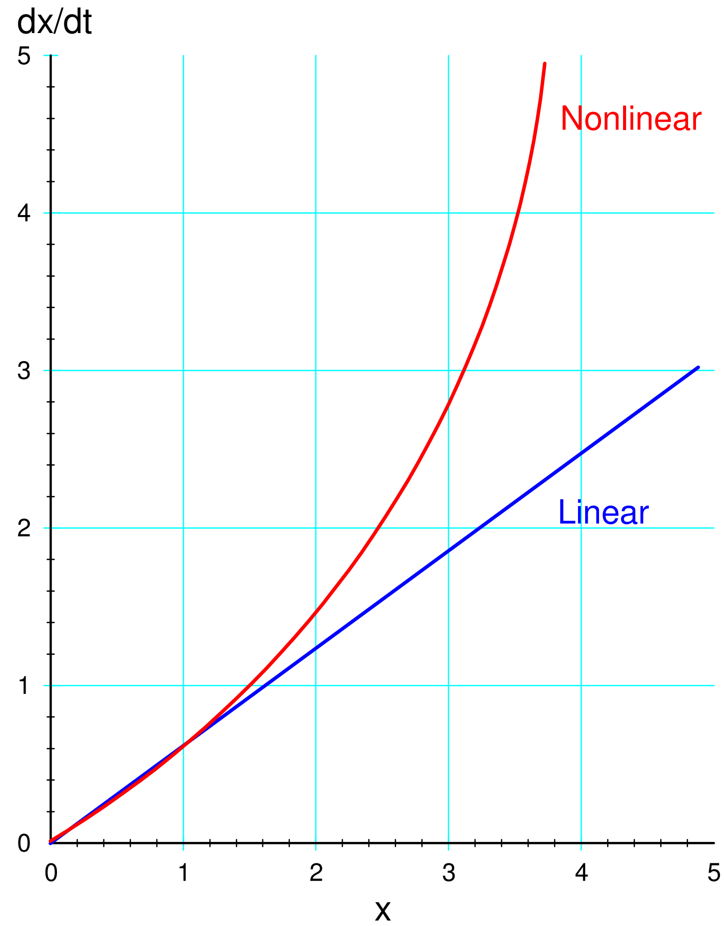
What if the plant is nonlinear?

$$\dot{x} = \sin(x)$$

$$\dot{x} = -x^3$$

How do you guarantee stability for these systems?

How do you find the "optimal" control law?



Nonlinear Control (cont'd)

A common approach is to use Lyapunov stability

- If the nonlinearities can be bounded,

$$\left|f(X)\right| < a$$

- Stability can be assured if the input is larger than that bound

$$(CX)^T(CAX + f(X) + CBU) < U$$

"Optimal" control is harder since our tools depend upon linear systems

- Linearize about multiple points
- Find the optimal control for each point
- Interpolate between optimal controllers

Robust Control

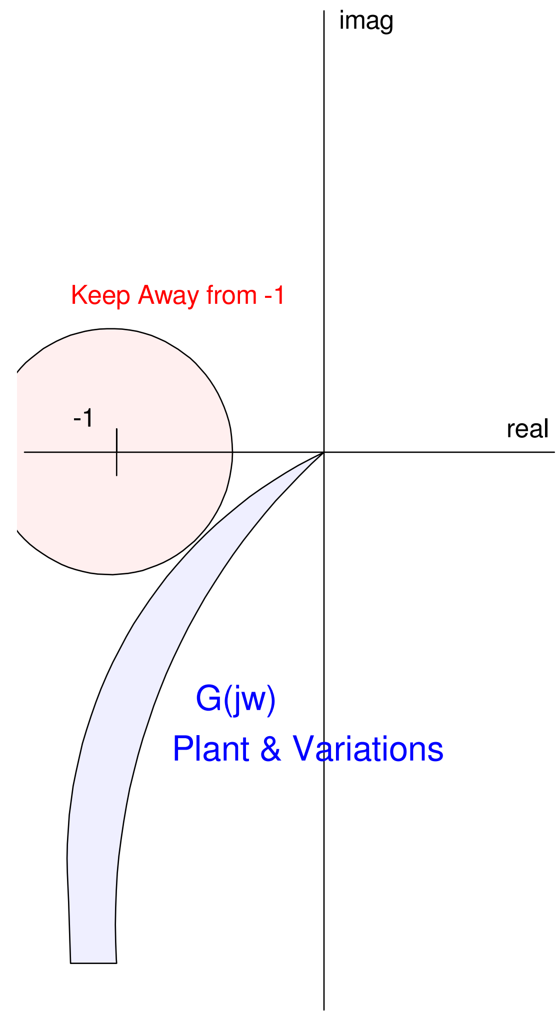
Problem: The linear model for a system actually varies

- -40C behaves different from +40C
- 0m vs. 5000m elevation has different air density, temperature humidity
- Full car vs. empty car
- New car vs. 100,000 miles

Can you design a controller that works well for a variety of systems?

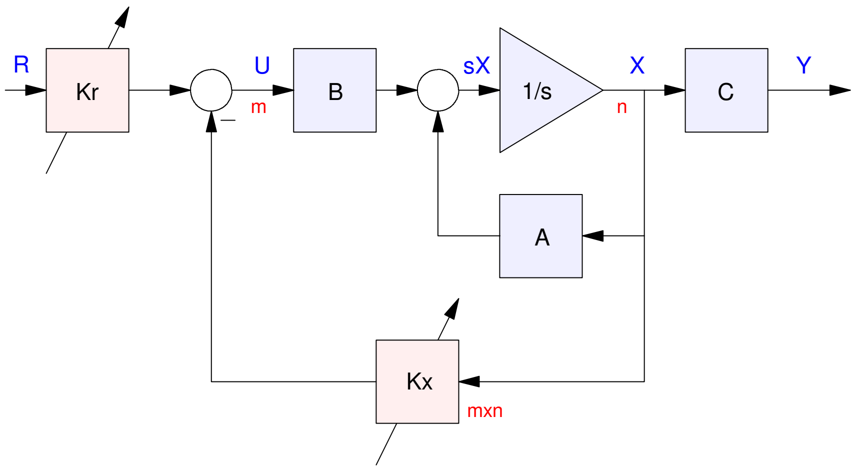
Solution tends to use frequency-domain techniques

- Instability when the open-loop gain is 1.000 at 180 deggrees
- Keep away from -1
- Use a generalized distance for MIMO systems



Adaptive Control

- Sometimes, the dyamics are unknown
- Sometimes, the dynamics are slowly time-varying



How do you adjust the control law so that the closed-loop response remains unchanged?

- In spite of not knowing the system's exact dynamics
- In spite of changes in the system's dynamics

How do you guaranteee stability?

- Result is a nonlinear system
- Limited tools for proving stability of nonlinear systems

Self-Tuning Regulators

- a.k.a. minimum variance control

The system's dynamics can be estimated using recursive least squares

$$y(k) = a_1 y(k-1) + a_2 y(k-2) + \ldots + b_0 u(k) + b_1 u(k-1) + b_2 u(k-2) + \ldots$$

u(k) can then be computed to drive y(k) to some desired value

$$u(k) = \frac{1}{b_0}(y(k) - a_1 y(k-1) - a_2 y(k-2) - \ldots - b_1 u(k-1) - b_2 u(k-2) - \ldots.)$$

Applications:

- Oil Tankers: Minimize the variance in the ship's heading
- Shipping: Dynamics vary with ocean depth

Issues:

- Using recursive least squares with a forgetting factor (heavier weight on newer data)
- Bursting: The gain goes to infinity if the input isn't sufficiently rich