Objective: Designing digital control systems.

These typically arise in one of two ways:

- The system we wish to control is digital.
  For example:
  - NYSE end of day prices;
  - Internet traffic;
  - Number of students in ECE 147b.
- The system is continuous and we are sampling it via an A/D board and actuating it via a D/A board.
  For example:
  - Electromechanical systems (robots, motors, vehicles);
  - Complex chemical production processes.
  - Biological processes.

The measurements and the actuation are also quantized. This may or may not be a significant issue in the control design.

Control is a hidden technology:

When it works well nobody notices!

Espresso machine:	1 or 2 loops (temperature, pressure).
Automobile:	5 to 20 control loops (engine, climate, brakes, radio)
Mars rovers:	10 to 20 control loops (navigation, speed control)
Aircraft:	50 or more loops (flight control, servos, redundancy)
Process control:	100 to 1000 control loops (levels, temperature, pressures)

And when it doesn't the results can be catastrophic.

Saab aircraft crash:	pilot/control system interaction
Chernobyl nuclear reactor:	operation at an unstable condition

Why digital?

Key aspects:

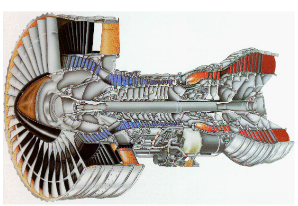
– Easily reprogrammed (cf. changing resistors/capacitors in an analog control circuit).
– Easier to implement complicated algorithms.
– Integration with remote systems and digital communication.
– More detailed user interface (terminal or web based).
– Cost is going down and speed is going up.

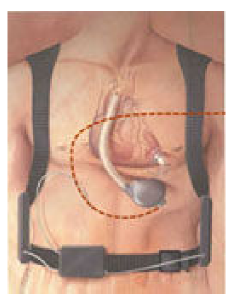
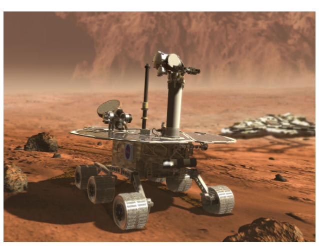
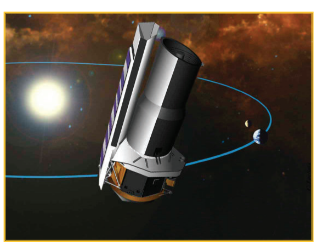
Why analog?

Some applications are still analog:

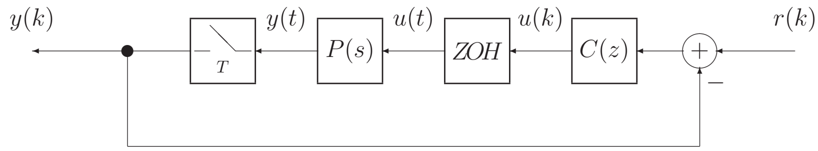
– Simple, mass produced systems (toaster, thermostat).
– Very high frequency control loops.
– Highly reliable simple control systems.
– On-chip integrated systems (e.g. electrostatic gyroscopes).

A few examples:




Typical digital control system

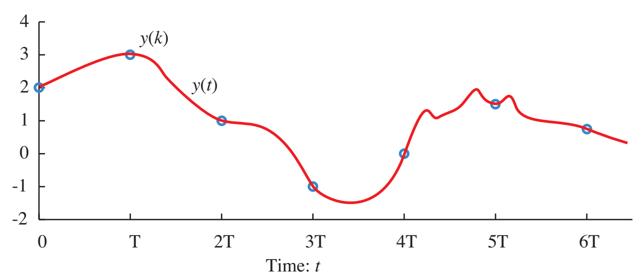


Components:

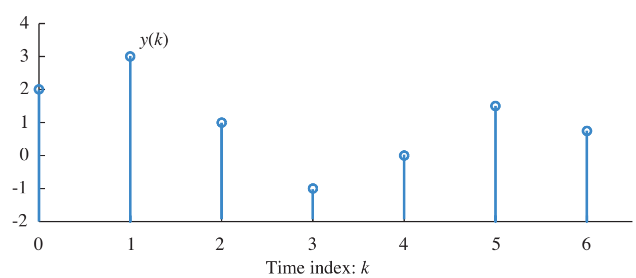
- Plant: $P(s)$, continuous time
- Controller: $C(z)$, discrete-time
- Sampler (A/D board): $y(k) = y(t)\mid_{t=kT}$ for $k = 0, 1, 2, \ldots$
- Zero-order-hold (D/A) board: $u(t) = u(kT)$ for $kT \leq t < kT + T$.

Sampler: $y(k) = y(t)\mid_{t=kT}, k = 0, 1, 2, \ldots.$ $\quad T$ is the sampling period.

Continuous signal:

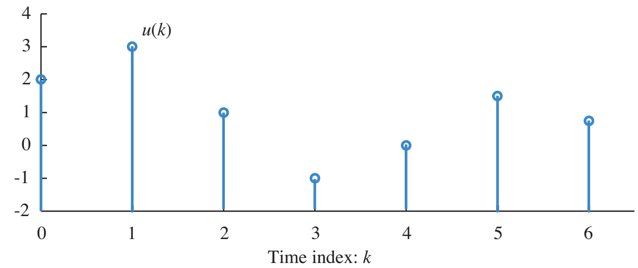


Discrete sequence:

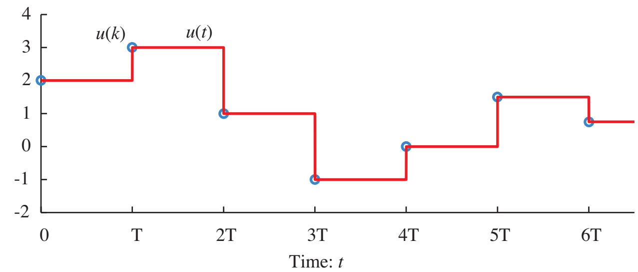


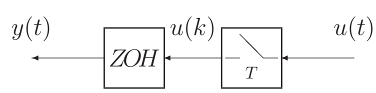
Zero-order hold: $u(t) = u(k), \quad \text{for} \quad kT \leq t < kT + T.$

Discrete sequence:

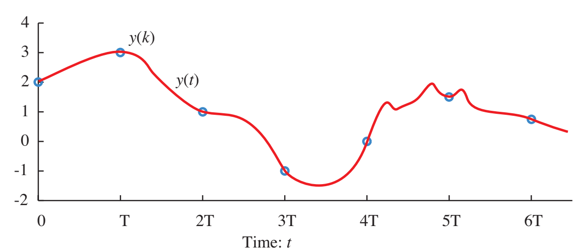


Continuous signal:

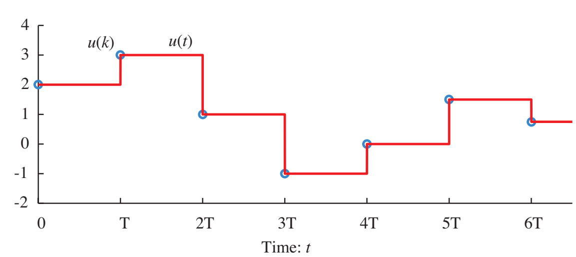




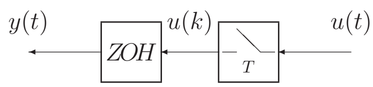
Input signal: $u(t)$

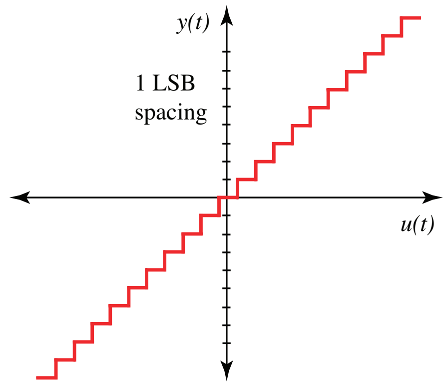


Output signal: $y(t)$



Quantization

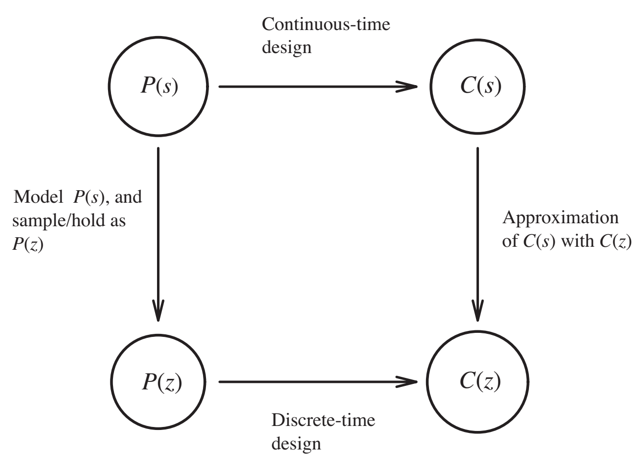




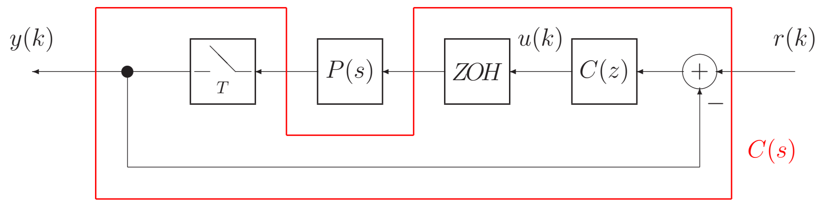
Potential error of $\pm 1/2$ LSB in the best case.

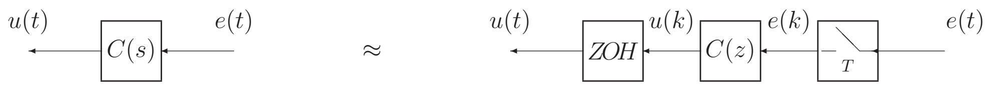
Example: 12 bit A/D and D/A on a ± 10 volt scale: 1 LSB = 0.00488 volts.

Objective: Design $C(z)$

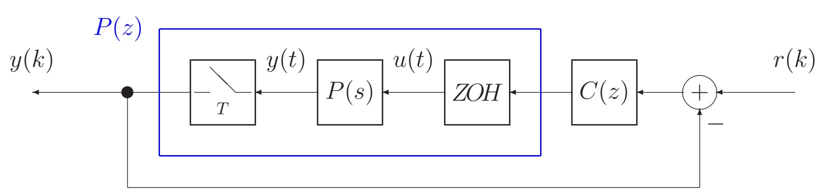


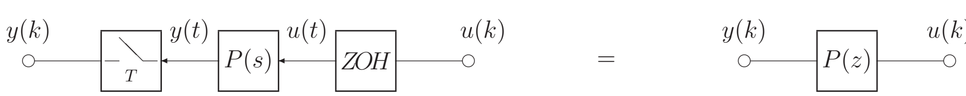
Approach: Design $C(s)$ and choose $C(z)$ to approximate $C(s)$



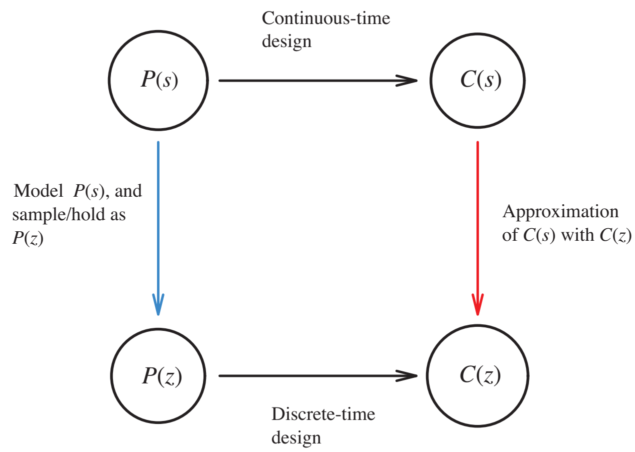


Approach: Model $P(z)$ (equivalent to $P(s)$ at samples), and design $C(z)$.





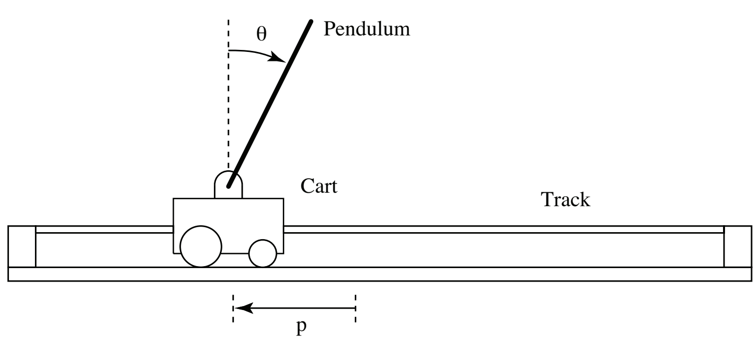
Objective: Design $C(z)$



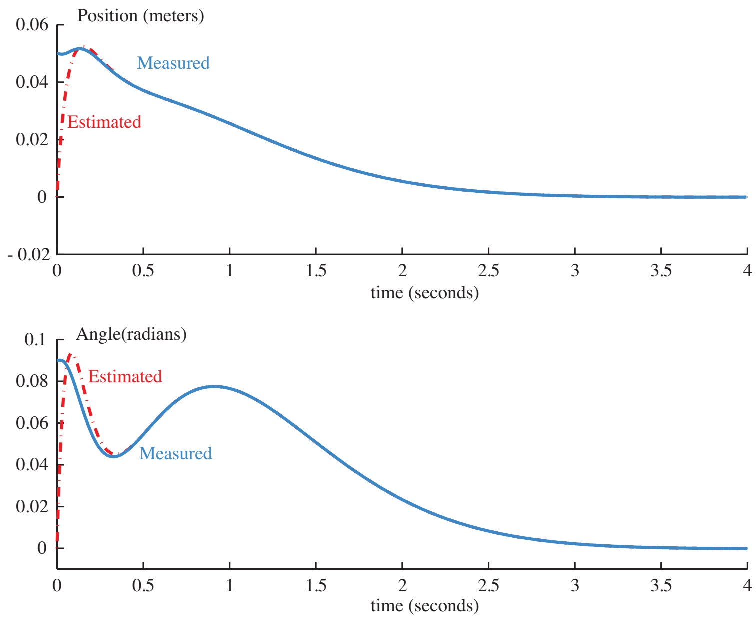
Preview: Inverted pendulum experiment

Balance the pendulum, $\theta = 0$, in the center of the track, $p = 0$.

Control is via a motor driven cart carrying the pendulum.



Preview: A successful design



Preview: A successful design