Sampled-Data Systems

Lecture #1

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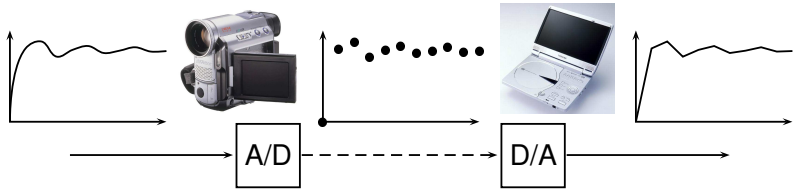
Outline

- Sampled-Data Systems: What and Why ?
- Design of Sampled-Data Systems
  - Conventional Methods
  - Goal of This Course
- Experimental Examples
  - Hard Disk Drive
  - Ultrasonic Motor

Sampled-Data Systems: What and Why ?

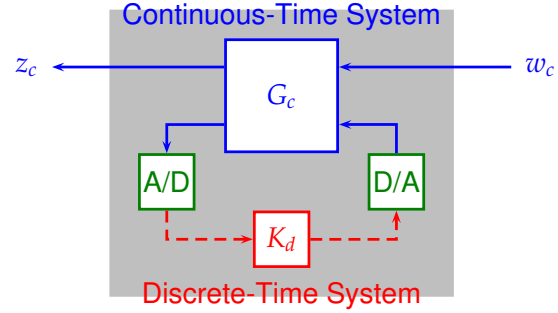
Sampled-Data Systems

- What: Interconnection of continuous-time and discrete-time systems through A/D (analog-to-digital) and D/A (digital-to-analog) converters
- Why: Development of digital technology
  → Most of engineering systems are SDSs



- Attention: Signals of interest are usually analog signals

Framework of Sampled-Data Systems

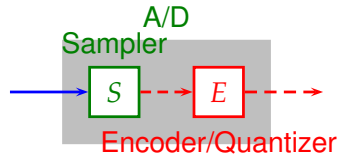


- Digital Control Systems
- Digital Signal Processing
- Digital Communication Systems

  ⋮

A/D and D/A Converters

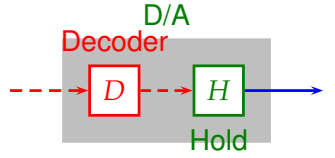
A/D Converter



- Sample: Discretization of domain of signal
- Encode/Quantize: Discretization of range of signal
  ← Digital computer can handle only finite number of values

D/A Converter

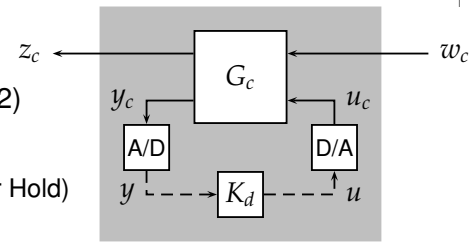
- Decode
- Hold



Assumptions

We assume

- G_c: FDLTI
- K_d: FDLTI (Lecture #2)
- A/D: Ideal Sampler
- D/A: ZOH (Zero Order Hold)



Ideal Sampler periodic sampling without encoding

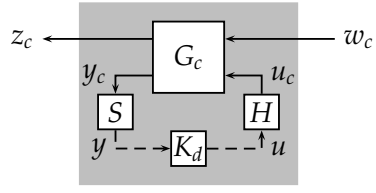
$$S : y_c \mapsto y, \quad y[k] = y_c(kh) \quad h > 0\text{: sampling period}$$

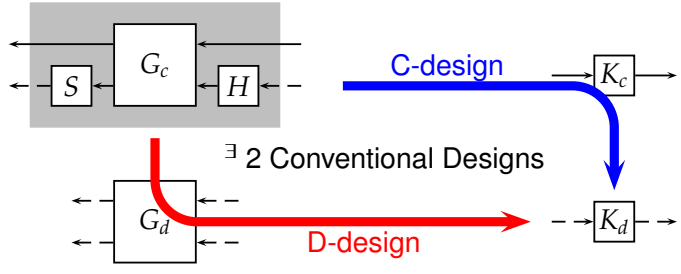
ZOH constant output through sampling interval

$$H : u \mapsto u_c, \quad u_c(kh + \theta) = u[k], \quad \theta \in [0, h)$$

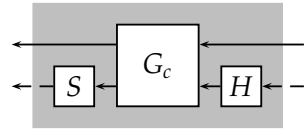
Motivation of Study (1/3)

- We are interested in design of K_d for given G_c, S, H
- How can we do it ?

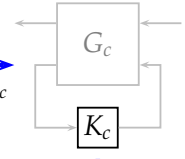




Motivation of Study (2/3): Conventional Design #1



Step 1
Find a good K_c for G_c

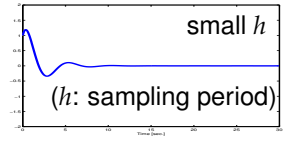


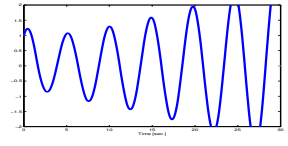
Step 2
Approximate K_c by K_d

Tustin transformation is typical:

$$K_d[z] := K_c\left(\frac{2}{h}\frac{z-1}{z+1}\right)$$

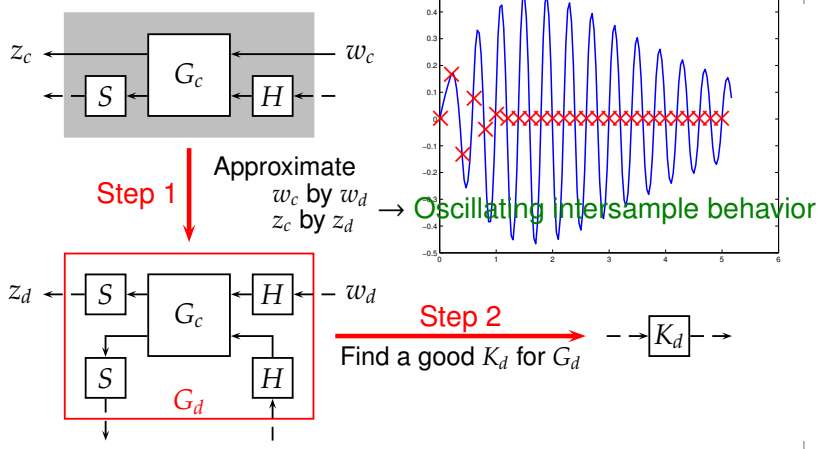
Bad News: Even stability is not guaranteed



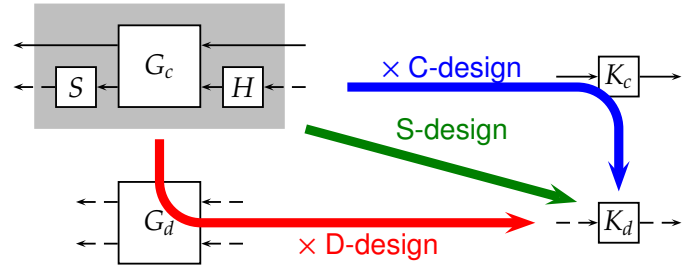


large h

Motivation of Study (3/3): Conventional Design #2



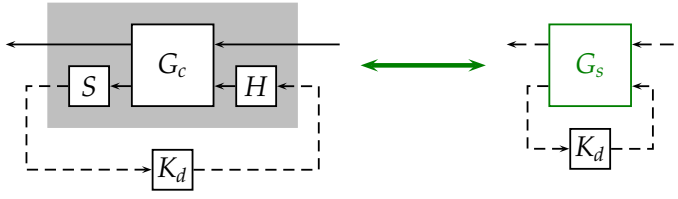
Goal of This Course (1/2)



Goal of This Course

- Design of K_d without approximation:
  Counterpart of LQ and $\mathbf{H}_\infty$ control
- Analysis as well

Goal of This Course (2/2)



We will derive a discrete-time system G_s which

- preserves stability and a specified performance index
- can depend on performance index
- is independent from K_d
- as a result, decomposes design procedure into
  - Step 1: Find G_s
  - Step 2: Find K_d for G_s

Schedule

L1 Sampled-Data Systems (1/6, 9.30–)
Introduction

L2 Review of Discrete-Time Control Theory (1/6, 11.00–)
Discrete-Time LQ Optimal Control

L3 Discrete-Time $\mathbf{H}_\infty$ Control (1/6, 13.30–)

L4 Sampled-Data LQ Optimal Control (3/6, 9.30–)
G_s for LQ Optimal Control

L5 Time-Invariant Model of SDS (3/6, 11.00–)

L6 Sampled-Data $\mathbf{H}_\infty$ Control (3/6, 13.00–)
G_s for $\mathbf{H}_\infty$ Control

- L2 + L4 → LQ Optimal Design
- L3 + L6 → $\mathbf{H}_\infty$ Design

References

We assume

- experiences on state-space control theory
- basic knowledge on $\mathbf{H}_\infty$ control theory

for continuous-time systems

Supplemental readings for course material:

- Chen, Francis: Optimal Sampled-Data Control, Springer (1995)
- Zhou, Doyle, Glover: Robust and Optimal Control, Prentice Hall (1996)

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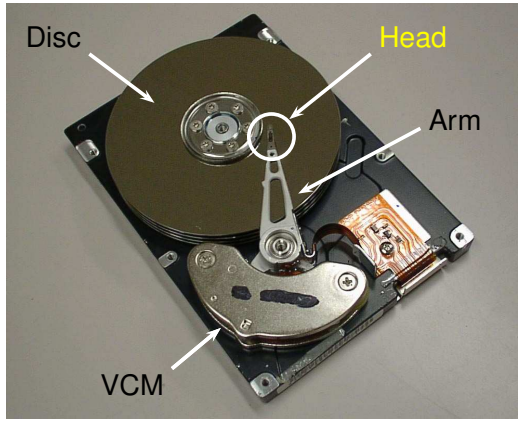
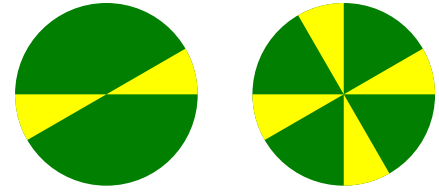
Hard Disk Drive



Control of HDD

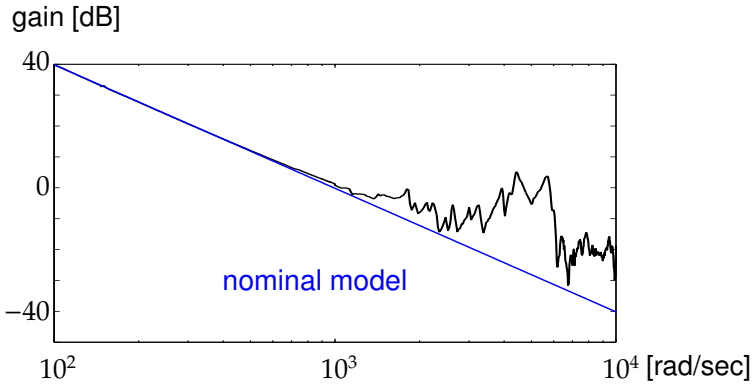
- High Capacity & High Performance
- Bad News: Sampling Period $\propto$ # (Position Information)



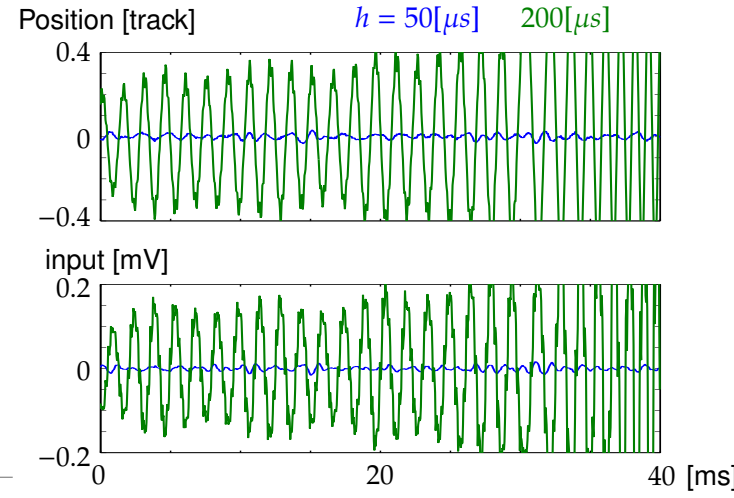
Position Information	Less	More
Data Area	More	Less

$\rightarrow$ Larger Sampling Period is Better

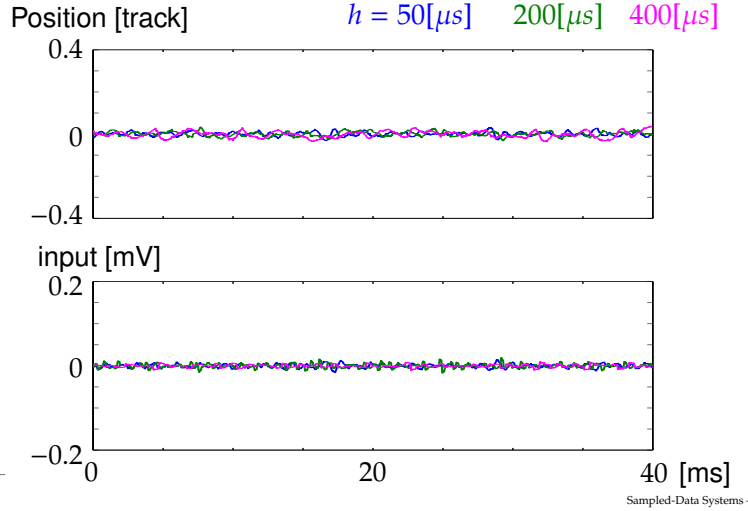
Frequency Response of HDD



Following Control of HDD: C-design



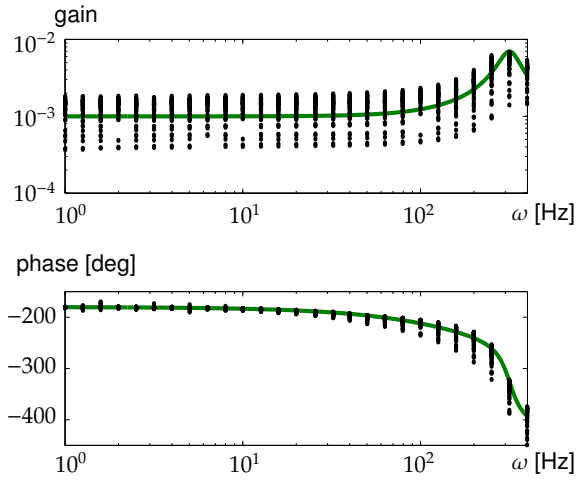
Following Control of HDD: S-design



Ultrasonic Motor

- Main application: AF SLR Camera
- Friction Nonlinearity

Frequency Response of USM



Speed Control of USM