Control Systems - 7^{th} Semester - Week 1

Dr. Salman Ahmed

November 2, 2021

Course Information

Course Title: Control Systems.

Course Code: CSE-310

Credit Hours Theory: 3hr

Credit Hours Lab: 1hr

Time Schedule:

- Lectures: Tuesdays and Wednesdays

Primary Textbook: Norman S. Nise, *Control Systems*, 8^{th} Edition.

Reference Textbook: R. C. Dorf. and R. H. Bishop, *Modern Control Systems*, 12^{th} Edition, Pearson

Instructor Information

Instructor: Dr. Salman Ahmed, Assistant Professor

Qualification:

- PhD majors in Control Systems, University of Alberta, Canada (2013)
- MSc majors in Signal Processing and Control Systems, Universiti Teknologi Petronas, Malaysia (2007)
- BSc in Computer Information Systems Engineering (Gold Medalist), UET Peshawar (2005)

Office: FYP Lab Offices

Email: sahmed@uetpeshawar.edu.pk

Control Systems

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- Forcing the output(s) of a system to have specific value(s)
- A system which processes the input to produce an output
- ...
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Where is control systems in this world?

Examples from Real-World

The paper that we use to write and make notes

The water that we drink from a tap or purifier (water control systems)

The medicines that a patient consumes (medicine control systems)

Homes:

- Thermostat to regulate the temperature
- Washing machines to clean dirty clothes
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Automobiles:

- Speed control, temperature control
- Stability in terms of shock absorber
- Anti-skid brakes such as ABS or traction control

Examples from Computing Systems Domain

In computing systems, many examples are available. I will discuss the following five examples in lecture.

1. E-business server
2. Apache web server
3. Email control server
4. Cache control system
5. Clock synchronization system

E-business server

E-business server (or e-trading server): Buying and selling using internet technology.

Usually, in a e-business server, we have certain requirements to meet. For-example:

- Purchase completion time should be less than 5 minutes (or a given specified time) (First priority)
- Throughput is greater than 1000 transactions per second (speed of database in measured by transaction throughput) (2nd priority)

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Designing an efficient e-business server which meets the above 2 requirements in real-time need some control knowledge. (Infact, sometimes in programming we are doing things which are common in control systems literature, and if know control systems literature, then the problem solution is much easier).

Let us move to another example of Apache Servers

Apache Web Server - Slide 1/4

Web server: A software or hardware which answers client requests related to world wide web. Most of the client requests are related to displaying of web-sites. Other requests are uploading and downloading data.

For example: if you want to goto Facebook website, or Geo-TV website, or live streaming of cricket matches, your browser sends HTTP requests to a webserver. The webserver finds the appropriate information, and fetches the data for you from that website.

Apache HTTP Server: A free, platform independent web-server software. Usually, it handles traffic from multiple customers.

Apache Web Server - Slide 2/4

On the Apache webserver side, we have threads or processes that facilitate (or deal with) customer requests.

You can imagine it as waiters in a restaurant serving customers (greeting them, finding a table for them, taking their order, communicating with kitchen, bringing food, and finally bringing the bill). A waiter is either busy or free (free when a customer leaves).

In computer networks, consider a network of 3 Apache webservers and the following objectives:

- Administrators want that each Apache server should not have more than 66% of CPU utilization
- If one Apache webserver fails, the remaining 2 webservers should absorb the entire load

Apache Web Server - Slide 3/4

An interesting research question: What should be the maximum number of client connections allowed to a web server?

Some connected users may not be doing anything on the server, while one user may be consuming too much resources (clicking on weblinks all the time)

Apache Web Server - Slide 3/4

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Another advanced level research question: What if administrative tasks start executing on the server (like anti-virus check or backup)

The answer to these questions: if control systems literature is known to a designer, then Apache web server system design is not difficult.

Apache Web Server - Slide 4

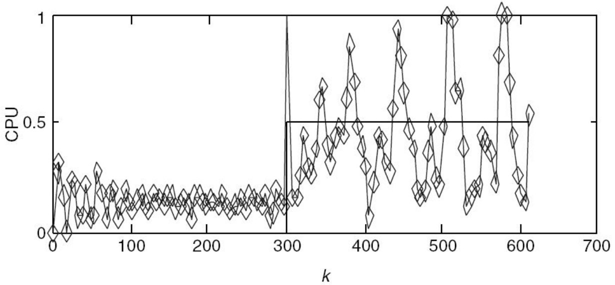

Figure: An example of a unstable Apache Network Server

- X-axis is time (discrete-time) and y-axis is CPU utilization
- During the first 300 seconds, the system is ok but after 300 seconds the systems oscillates

Email Control System - Slide 1/2

Email server: a computing system which sends and receives emails (Forexample: Gmail server)

Email server uses a database with which clients or end-users can interact.

For example, clients access e-mail by opening an e-mail database, obtaining a view of the elements in the database, and then reading, updating, deleting, and inserting entries in the database.

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The interaction between the client and server is in the form of remote procedure calls (RPCs).

Important variable: We need to pay attention to the number of RPCs currently being processed by the server, and in some cases limit the maximum number of RPCs.

Email Control System - Slide 2/2

We have not talked about service differentiation yet

Some users are more important (example in case of university email server: VC, Dean, Registrar, Chairman) - the RPC of these users always need to be entertained (cannot discard)

Cache Control System - Slide 1/2

Cache: a temporary storage area in computing systems

Cache hit: when the requested data can be found in a cache

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Webservers, CPUs and hard disks drive systems frequently use caching systems. Web browsers employ web caches to store previous responses from web pages and images. Question: Which data to keep in cache?

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Answer: Data with highest probability of being accessed next

Performance analysis of caching system: In terms of average access time

Cache Control System - Slide 2/2

Access time to cached page is less than accessing a page in store, so hit probability is important

Consider a web content service provider that has several classes of customers, differentiated by how much they pay for the service.

First questions: What should be the size of memory pool?

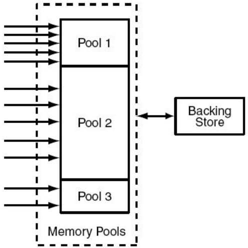

Figure: An example of a caching system that supports differentiated services.

Clock Synchronization System

Examples from Computing Systems Domain

There are more examples in computing systems domain such as streaming media, load balancing, congestion avoidance in routers any many more.

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When you computer or laptop or cell-phone hangs, what is this phenomenon

It is actually that your system is unstable, and you need to press ctrl + alt + delete or restart your phone

Advanced Research Areas in Control Systems

Research areas:

- Feedback control of computing systems: Computing systems are already present and we interact with them in our daily life. However, they were designed by computer scientists having little knowledge of control engineering. I supervise PhD students in this area.
- Smart grids: application of computing systems to power systems. I supervise numerous MSc students in this area.

And more recently, I moved to cyber security area where we are working on security protocols for IoT devices.

Course Outline

In chapters 2 and 3, we study the language of transfer functions and state-space to obtain mathematical model of systems.

In chapters 4, 6 and 7, we will study tools to analyze those models.

In chapters 9, 10, 11 and 12, we will study tools to design controllers for these models.

In summary, control course is about modeling, analysis and design of systems

Chapter 2 - Review of old concepts

Broadly, we have 2 types of mathematical equations:

- Linear static equations e.g. $y = mx + c$
- Differential equations e.g.

$$\frac{d^2y}{dx^2} - x\frac{dy}{dx} = u$$

Laplace Transform: Working with differential equations is difficult, so we transform them to Laplace domain (and then solve them).

Example 2.3

Obtain the Laplace transform of the following differential equation (assume zero initial conditions)

$$\frac{d^2y}{dt^2} + 12\frac{dy}{dt} + 32y = 32u(t)$$

Solution: Taking Laplace transform, we obtain the following:

$$\begin{aligned} s^2Y(s) + 12sY(s) + 32Y(s) &= \frac{32}{s} \\ (s^2 + 12s + 32)Y(s) &= \frac{32}{s} \\ Y(s) &= \frac{32}{s(s^2 + 12s + 32)} \end{aligned}$$

Transfer function

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Figure: Transfer function

Transfer function Symbol

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The answer is yes, but if A denotes voltage, B denotes current and C denotes resistance.

V is popular symbol to denote voltage and similarly I for current and R for resistance.

A transfer function can be denoted by any alphabet from A to Z, but popular symbols are $G(s)$, $P(s)$, $H(s)$ and $T(s)$.

Abusive notation is G, P, H and T [ignoring the brackets and s term i.e. ignore (s)]

Transfer function Analysis

Zeros: Roots of numerator of a transfer function.

Poles: Roots of denominator of a transfer function.

What information do poles and zeros convey (you have already learnt this in DSP)?

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Poles: Roots of denominator of a transfer function.

What information do poles and zeros convey (you have already learnt this in DSP)?

A continuous-time system is stable if all poles are negative.

A discrete-time system is stable if all poles are within unit circle.

Stability Definition

Absence of input: If the output goes towards zero (or an equilibrium point), then the system is stable.

Presence of bounded input: If the output remains bounded, then the system is stable.

Sometimes, we call it BIBO stability. Going back towards our discussion:

If all poles are negative, then the system is stable (both cases).

Stability Analysis

Example: Compute the poles, zeros and analyze stability of the following seven transfer functions:

$$G_1(s) = \frac{(s-3)}{(s+5)}$$

$$G_2(s) = \frac{(s-3)}{(s-5)}$$

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$$G_3(s) = \frac{(s-3)(s+2)}{(s+5)(s-10)}$$

$$G_4(s) = \frac{s(s+2)}{(s+5)(s-10)}$$

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$$G_5(s) = \frac{3s}{(s+5)(s-10)}$$

$$G_6(s) = \frac{3s}{2s(s+5)(s-10)}$$

$$G_7(s) = (s+3)(s+5)$$

Obtaining Model

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Model of a car, or model of a fan, or model of human hand

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We need law of physics, circuits, mechanics, chemical engineering to model physical systems.

In next lecture, we will begin with obtaining model of RLC circuits.

Till then, revise the following six formulas:

$$V_R = I_R R$$

$$i_c = C\frac{dv_c}{dt}$$

$$v_L = L\frac{di_L}{dt}$$

Mechanical Systems

In electrical circuits, we apply KCL and KVL (sum of voltages in a loop is zero or sum of currents at node is zero) .

Mechanical systems obey Newton law; the sum of forces equal to zero (or sum of applied forces equals sum of transmitted/reactive forces).

There are three basic elements of mechanical systems

- Mass
- Spring
- Damper

Mechanical Element - Mass

Mass: Inertial element usually denoted by M.

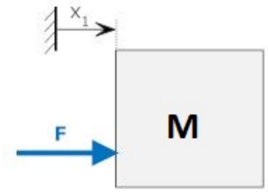


Figure: Schematic and Symbol of Mass

$$F = Ma = M\frac{dv}{dt} = M\frac{d^2x_1}{dt^2}$$

If we reverse the direction of x_1, then we write the following:

$$F = -Ma = -M\frac{d^2x_1}{dt^2}$$

Mechanical Element - Spring

Spring: Element that can store or release energy depending upon force applied (compress/expand). Usually denoted by $\boldsymbol{K}$ (Actually $\boldsymbol{K}$ denotes stiffness of spring).

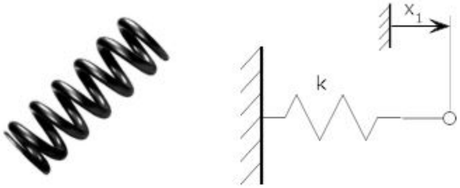


Figure: Schematic and Symbol of Spring

A spring obey Hooke's law, as expressed below:

$$\boldsymbol{F = K x_1}$$

Mechanical Element - Damper

Damper: An element that dissipates or absorb energy. Usually denoted by D (but book denotes it by f_v).

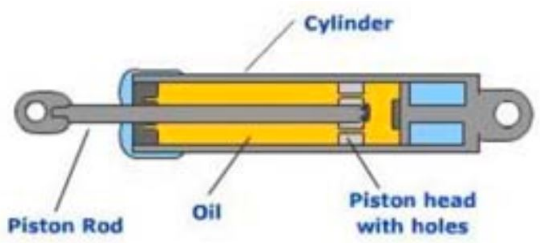
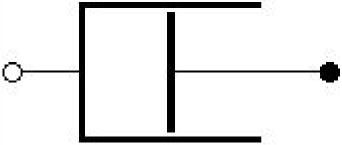


Figure: Schematic of Damper

If the fluid cannot move easily, we drill a hole inside the piston head.

Normally, fluids which are less compressible are chosen (based on application of damper)

Mechanical Element - Damper



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$$F = f_v \frac{dx}{dt}$$

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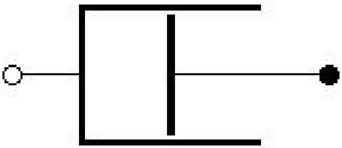

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$$F = f_v \frac{dx}{dt}$$

As usual as I say koi question koi confusion to poochay. Nahei hai, to inshaAllah aglay haftay mulaqat hogee