Introduction to Control (00340040) lecture no. 1

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Outline

General info

Course web site: `http://leo.technion.ac.il/Courses/IC/`
Prerequisite (must): Linear Systems M (00340032)
Musts from LS:

- Laplace transform and signals in s-domain, initial and final value theorems, etc
- transfer functions and their properties (poles, zeros, static gain, etc)
- stability and the Routh–Hurwitz criterion
- signals and systems in the frequency domain
- frequency response and frequency-response plots (Bode and polar) of LTI systems
- 1st and 2nd order dynamical systems (definitions, step/frequency responses, etc)
- ~~sampling in time and frequency domains~~
- linearization

Grading policy:

- Project with lab parts (provided the final exam grade ≥ 55): 30%
- Final exam: 70–100%

The use of books / lecture notes is not permitted during exams.

Topics

1. Block diagrams
2. Modeling, DC motors
3. Steady-state and transient requirements
4. Open-loop control, plant inversion
5. Closed-loop control
6. Internal stability
7. Root locus method
8. Nyquist stability criterion
9. Basic loop shaping and stability margins
10. Dead-time systems
11. PID controllers and their tuning
12. ~~Sampled-data control basics~~

Outline

Course info

Introduction

Block diagrams

What is "control"?

Roughly, control is the discipline studying how to

- change behavior of systems

(mechanical, electrical, chemical, biological, economical, etc) so that they

- behave in a desirable manner.

Control is

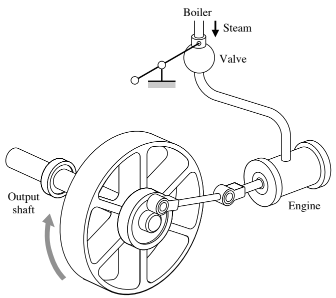
- relatively young field

(as separate discipline—since '40s), yet control systems

- appear nowadays practically everywhere,

in homes, in industry, in communications systems, in vehicles, in scientific instruments, etc. Nature also offers a plenty of examples of sophisticated and successful control systems (biological systems, ecosystems, etc).

Example 1: steam engine

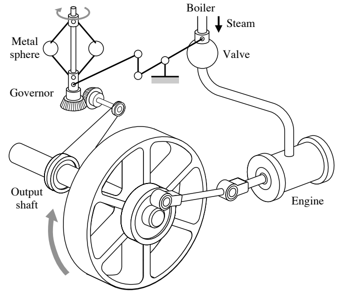


Problem: maintain rotation speed at a constant predetermined level

Actuator: throttle valve can regulate the admission of steam into cylinders

Obstacles: unpredictable changes (uncertainties), like
- load
- steam pressure
- engine / valve aging
- . . .

Steam engine: centrifugal governor



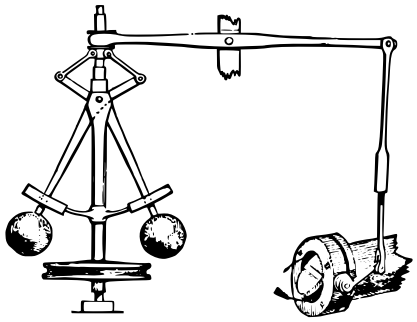
Solution adapted[1] by James Watt in 1788 did the trick: if properly tuned,

- the governor maintains a near constant speed

whatever the load or fuel supply conditions are.

[1] It was not Watt's invention: centrifugal governors were used to regulate the distance and pressure between millstones in windmills since the 17th century.

Centrifugal governor: idea



When rotation speed increases,

– balls move outwards, reducing the valve aperture and steam admission

When rotation speed falls,

– balls move inwards, increasing the valve aperture and steam admission

This operation principle called feedback control.

Steam engine: the neverending story

– The first automatic control system used in industrial processes
  Watt's governor tamed steam engine and made the Industrial Revolution possible

– Tuning centrifugal governors turned out to be not simple at all
  Too enthusiastic governor could cause oscillatory motion of steam engine (*hunting* phenomenon).

– This catalyzed the development of rigorous theory (by J. C. Maxwell)
  The problem reduces to the question about *stability* of differential equations

– Verifying stability turned out to be not quite simple

– This catalyzed further development of mathematical tools (by Routh, Hurwitz, et alii)

– . . .

Example 2: blood glucose regulation

Glucose, transported via the bloodstream, is

– the primary source of energy for body's cells.

Its

– concentration must be kept within a narrow level around 90 mg/dL

(normally, 70–120 mg/dL, might be higher after meals). Failure to maintain this range consistently (hyperglycemia[2] or hypoglycemia) is very dangerous.

[2] Chronic hyperglycemia (even in fasting states) most commonly caused by diabetes.

Blood glucose regulation mechanisms

Glucose "stocked" in the form of glycogen, which is produced, stored, and cleaved in the liver.

– When blood glucose levels are in excess, glucose can be stored in the liver as glycogen (glycogenesis).

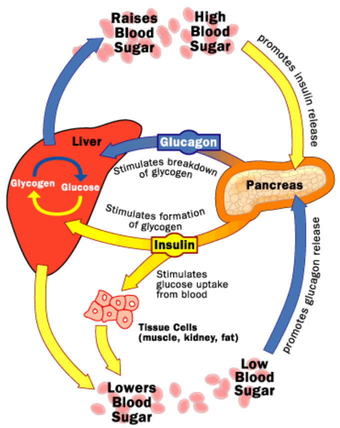
– When glucose levels in the blood stream are low, the glycogen can be catabolised and glucose may re-enter the blood stream.

Blood glucose level monitored by cells in the pancreas.

– If blood glucose level falls, α-cells of the pancreas release *glucagon*, a hormone causing liver cells to release glucose from glycogen.

– If blood glucose level rises, β-cells of the pancreas release *insulin*, a hormone causing liver cells to convert more glucose into glycogen, thus decreasing blood sugar levels.

Blood glucose regulation



Problem: maintain blood glucose level constant

Actuator: liver (via glycogen)

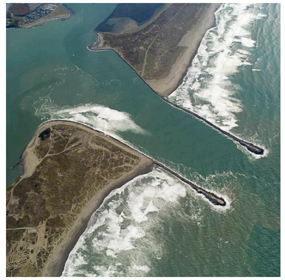
Obstacles: unpredictable changes (uncertainties), like
- irregular meals
- irregular physical exertions
- stress
- ...

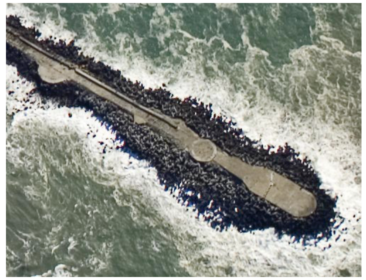
Sensor: pancreas cells

Controller: pancreas cells (via glucagon / insulin)

This is nothing but a
- feedback control system

Example 3: breakwater





Breakwater is a barrier built out into a body of water to protect a coast or harbor from the force of waves. The idea is to
- dissipate the energy of waves

by properly designed offshore constructions[3].

[3] Although there is no feedback (even no inputs / outputs) involved, this system can still be considered control system (yet not of the type we'll study)—we change behavior of the system to achieve our goals.

What this course is about ?

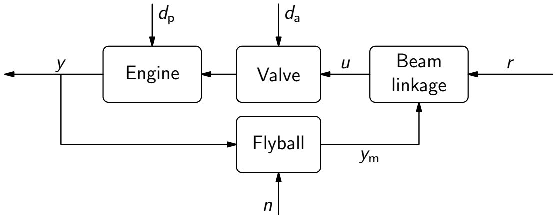
This course aims at providing
- primary insight into the principles of automatic control systems

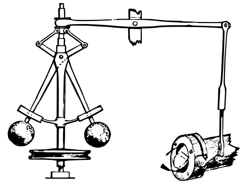
as well as at introducing some
- basic theoretical methods of control systems analysis and design.

We'll confine ourselves to
- continuous-time systems
- input / output approach
- LTI (linear time-invariant) SISO (single-input / single-output) models
- single-loop feedback

Outline

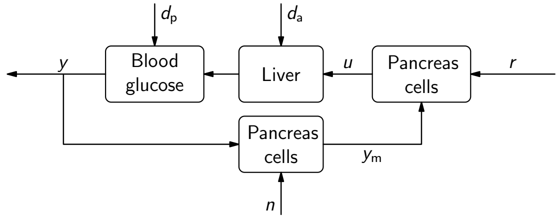
Block-diagram of centrifugal governor

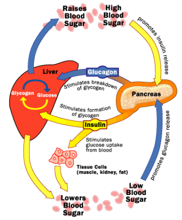




- r: required rotation speed
- u: throttle valve opening
- y: shaft rotation speed
- y_m: thrust bearing position
- d_p: plant disturbance
- d_a: actuator disturbance
- n: measurement noise

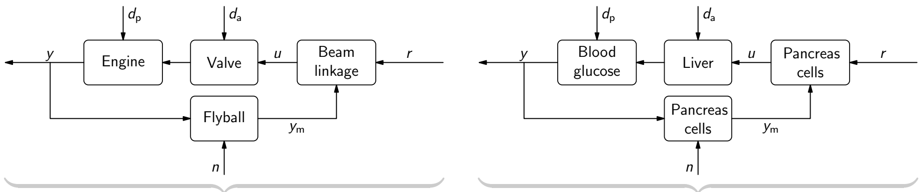
Block-diagram of blood glucose regulation





- r: required glucose level
- u: hormones (insulin / glucagon)
- y: blood glucose level
- y_m: glucokinase (enzyme)
- d_p: plant disturbance
- d_a: actuator disturbance
- n: measurement noise

Different nature / identical logic



Centrifugal governor — Blood glucose regulation

Despite

- completely different nature of their components,

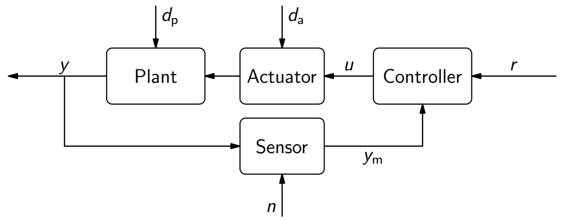
these control systems have

- identical operation logic.

Hence, from the control viewpoint they can be described by the same block diagram and

- studied by the same methods.

Abstract control system



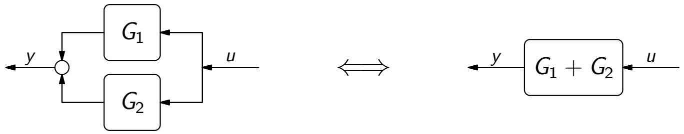
- r: reference signal
- u: control signal (input)
- y: controlled signal (output)
- y_m: measured signal (output)
- d_p: plant disturbance
- d_a: actuator disturbance
- n: measurement noise

Control design problem:

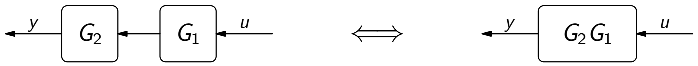
- given plant, sensor and actuator
- design controller guaranteeing required behavior of y

Block-diagrams: basic connections

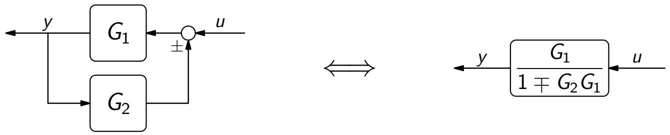
Parallel ($y = (G_1 + G_2)u$):



Series / cascade ($y = G_2 G_1 u$):

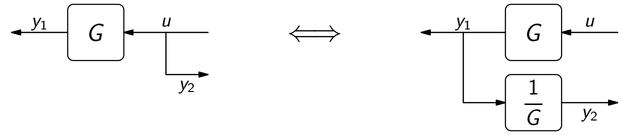


Feedback ($y = \dfrac{G_1}{1 \mp G_1 G_2} u$):



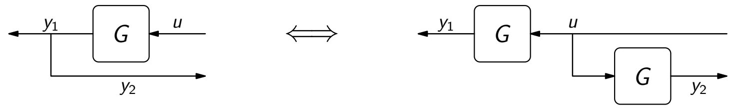
Block-diagram manipulation rules: pickoff points

Moving pickoff point behind a block:



Both diagrams describe the relationships $y_1 = Gu$ and $y_2 = u$.

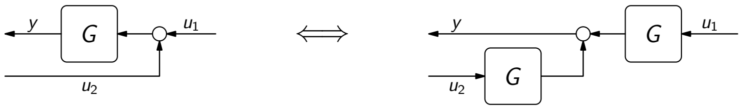
Moving pickoff point ahead of a block:



Both diagrams describe the relationship $y_1 = y_2 = Gu$.

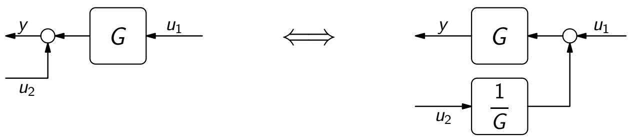
Block-diagram manipulation rules: summing points

Moving summing point behind a block:



Both diagrams describe the relationship $y = G(u_1 + u_2)$.

Moving summing point ahead of a block:



Both diagrams describe the relationship $y = Gu_1 + u_2$.

Example