Automatic Control

If you have a smart project, you can say "I'm an engineer"

Staff boarder

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Instructor

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Automatic Control
MPE 424

- **Course aims:**
  - **Understand the mathematical modeling of other systems**
  - **Understand the different classic control strategies**
  - **Understand and design the control systems**
  - **Create and innovate the real model to simulate the some cases**
- **References**

- Dorf, R. C., & Bishop, R. H. (2001). Modern control systems. Upper Saddle River, NJ: Prentice Hall. (Ref-01)
- Ogata K. (2002). Modern Control Engineering. 4th ed.,Prentice Hall, New Jersey. (Ref-02)

Course plan

week	Date	Contents	Requirements	Laboratory	References	Marks	Instructor
1	12-2	Introduction Syllable/Course specs Control system classifications Laplace transform			Ref-01		Dr. Mostafa Elsayed
2	19-2	Modeling - Mechanical system - Hydraulic system	Project idea and team names	DC-Motor control			
3	26-2	Modeling - Electrical system (motors and combined systems)	Quiz			5/3 quizes	
4	5-3	Block diagram Transfer function and State space		Electrical-mechanical analogy			
5	12-3	Time Response (1^{st} and 2^{nd} order)	Quiz			5/3 quizes	
6	19-3	Steady state Error Stability analysis	Progress report	Filters			
7	26-3	Midterm				15	

Course plan

week	Date	Contents	Requirements	Laboratory	References	Marks	Instructor
8	2-4	Frequency Response Nyquist plot	Reports (smart building)	DC- motor Kit	Ref-01	5	Dr. Mohamed Saber Sokar
9	9-4	Frequency Response Bode Plot	Quiz	Operational amplifier circuits		5/3 quizes	
10	16-4	Design Controller and system compensation			Ref-02		
11	23-4	Design PID controller Optimal and LQR control					
12		Receive project				15 for project and report	

Evaluation rules

Report Contents

- Research plane
- Aim
- Tools/facilities
- Methodology/control strategy
- Experimental works
- Result/ conclusions

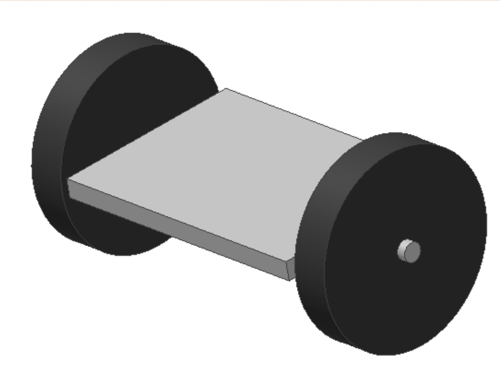
Marks distribution

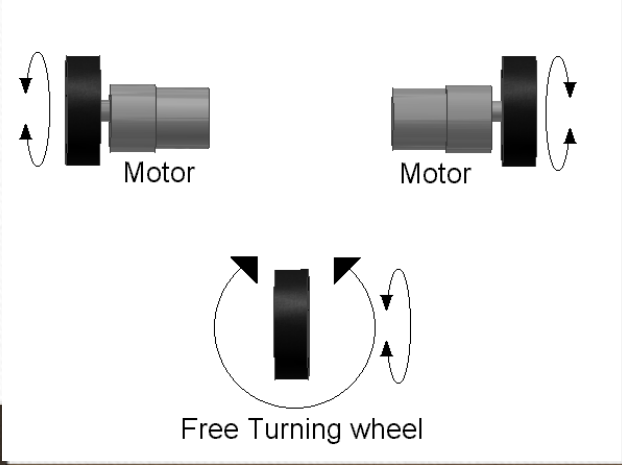
Marks \ assessments	Assessments		Final Exam	Total
	• MidTerm	15	70	
	• Projects	10		
	• Report & Quize	5		
TOTAL		30	70	100

Projects

8

- **Line Follower Robot Steering Mechanism**
  - **Design mechanism**
    - Theory of machine
    - Machine design
  - **Classification (only one)**
    - **2-wheeled robots**
    - **3-wheeled vehicles**
    - **4-wheeled vehicles**
      - **2 powered, 2 free rotating wheels**
      - **2-by-2 powered wheels for tank-like**
      - **Car-like steering**
    - **5 or more wheeled vehicles**





Projects

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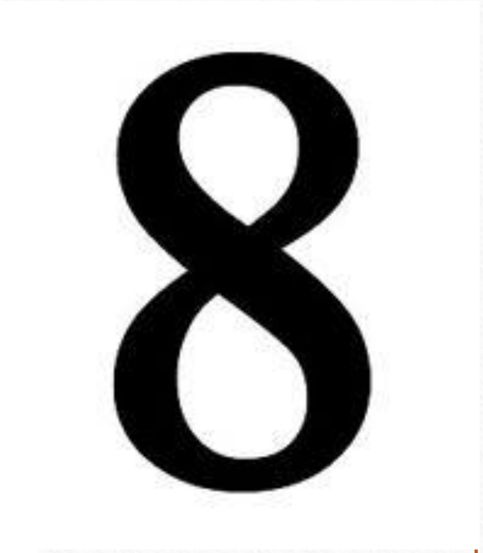
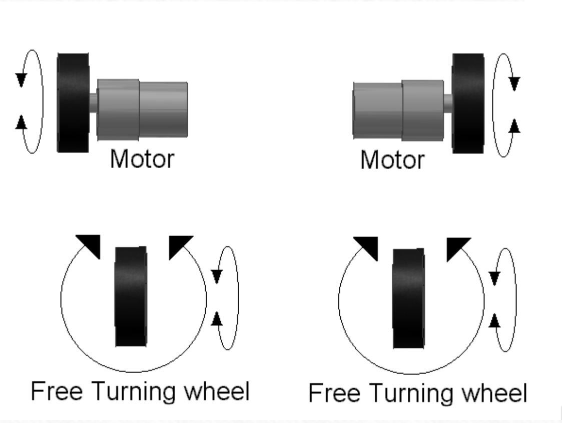
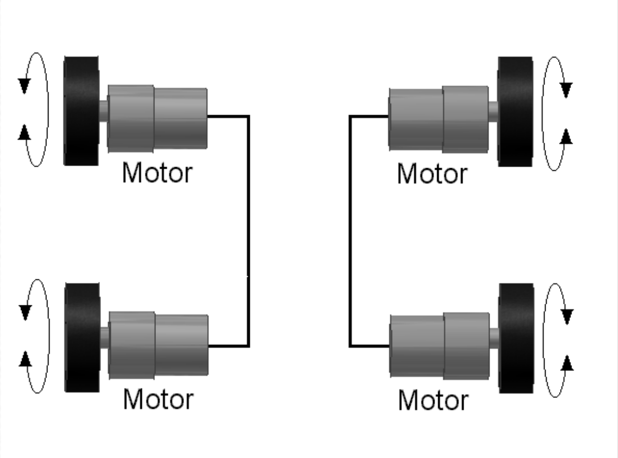
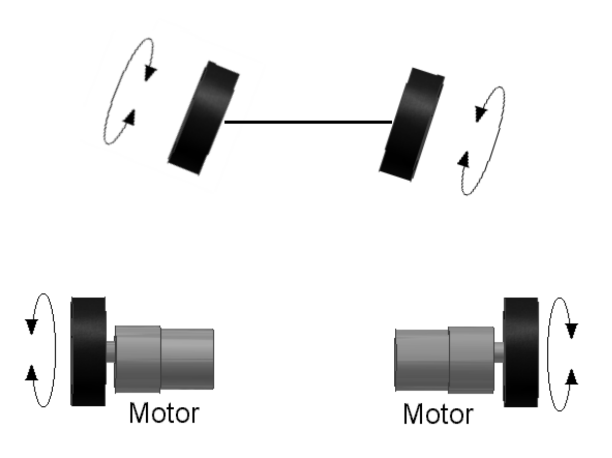






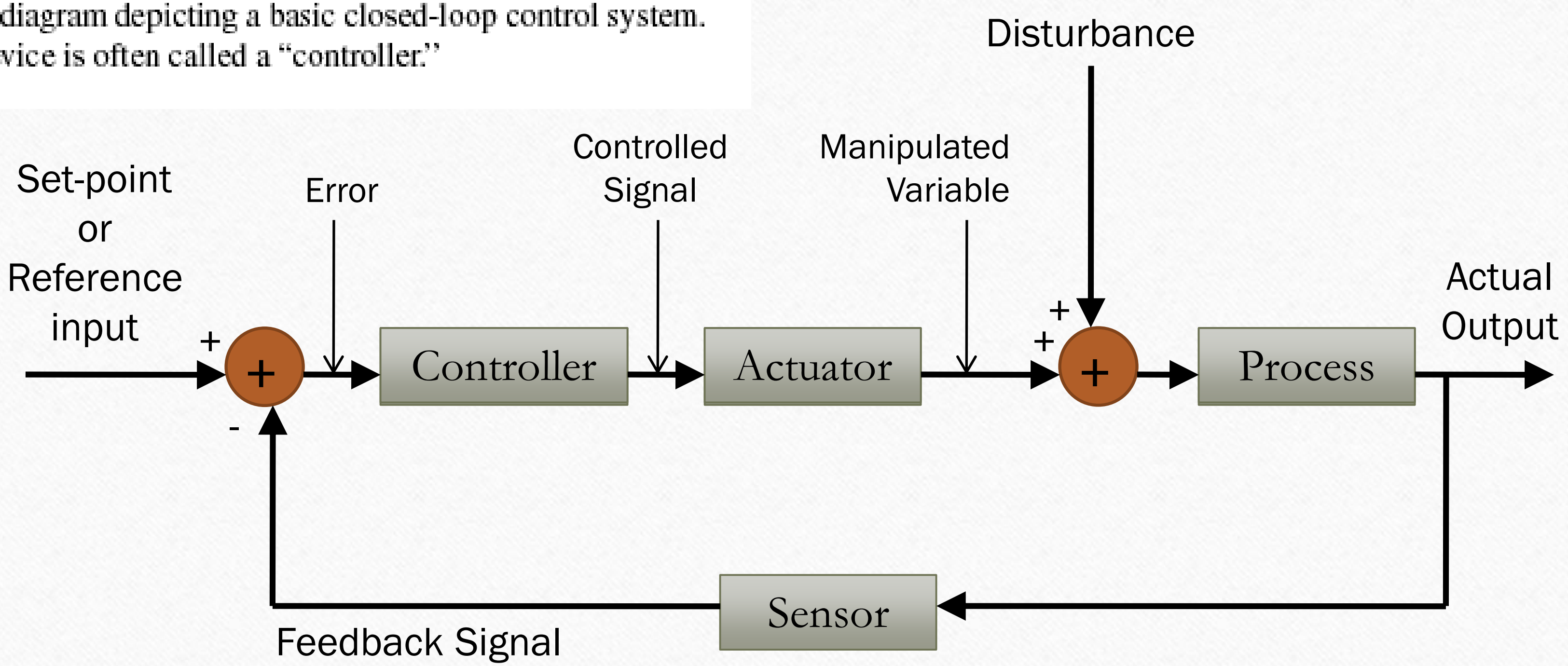


Automatic Control

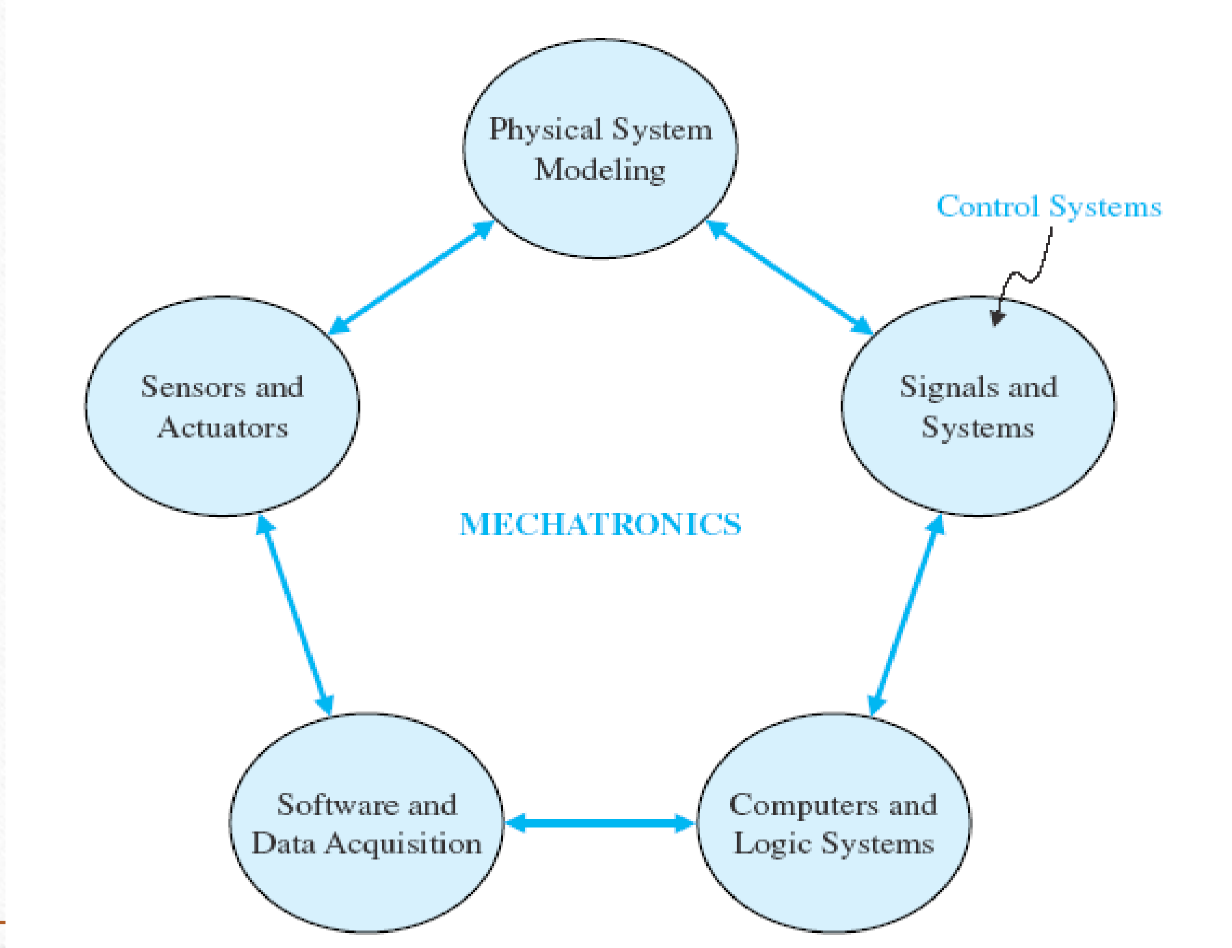
- **Lecture aims:**
  - Understand a definition of a control system
  - Facilitate combining and manipulating differential equations

Automatic control system

A negative feedback system block diagram depicting a basic closed-loop control system.
The control device is often called a "controller."



Automatic control system



Automatic control system

Must have fundamental method for modelling many physical systems:

- Equation of motion
  - Mechanical
  - Electrical
  - Hydraulic
  - Thermal

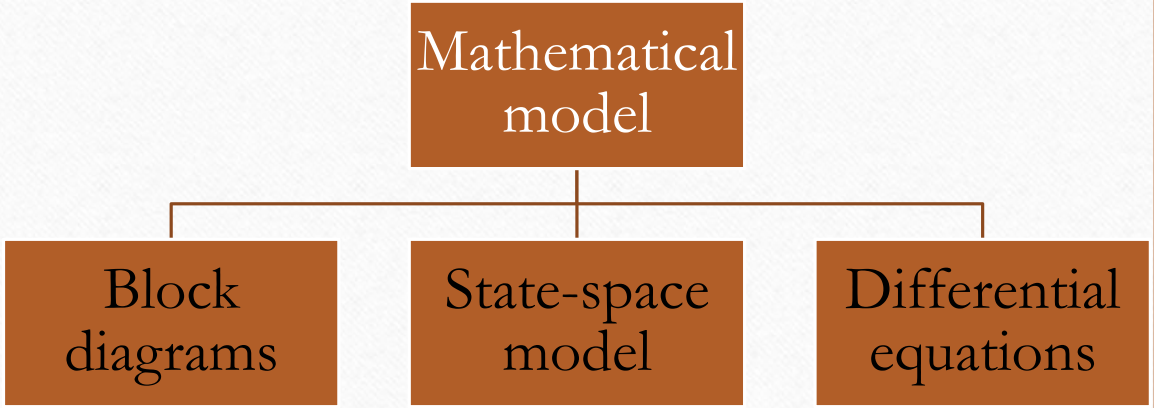
Must have fundamental method for modelling many physical systems:

- Equation of motion
  - Newton’s method
  - Energy method
  - Lumped method
  - Lagrange’s method

Automatic control system

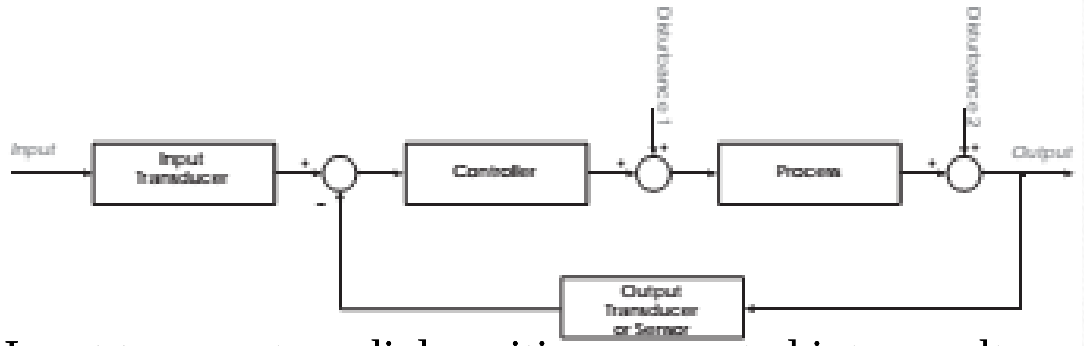
Mathematical Models for the Schematic

- **Understand the physical system and its components**
- **Make appropriate simplifying assumptions**
- **Use basic principles to formulate the mathematical model**
- **Write differential and algebraic equations describing the model**
- **Check the model for validity**



Automatic control system

Closed-Loop Control System

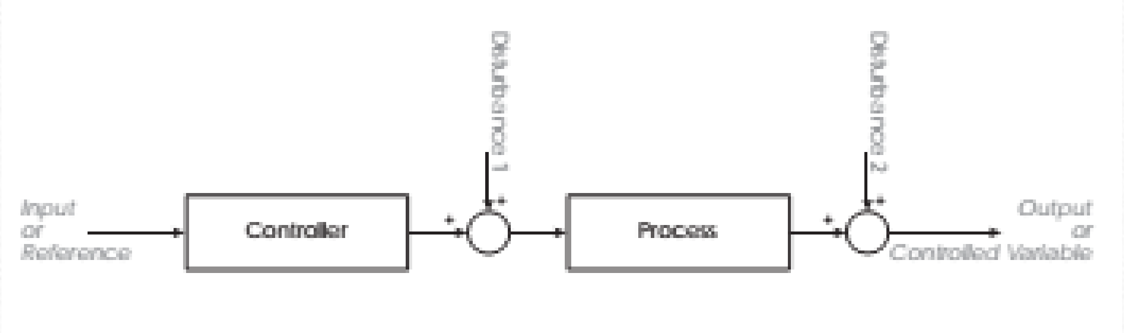


Input temperature dial position converted into a voltage by a potentiometer.

Output temperature converted to a voltage by a thermistor.

Differencing circuit subtracts output from input result is actuating signal controller drives the plant only if there is a difference

Open-Loop Control System



Process is a boiler, input is fuel, output is heat.

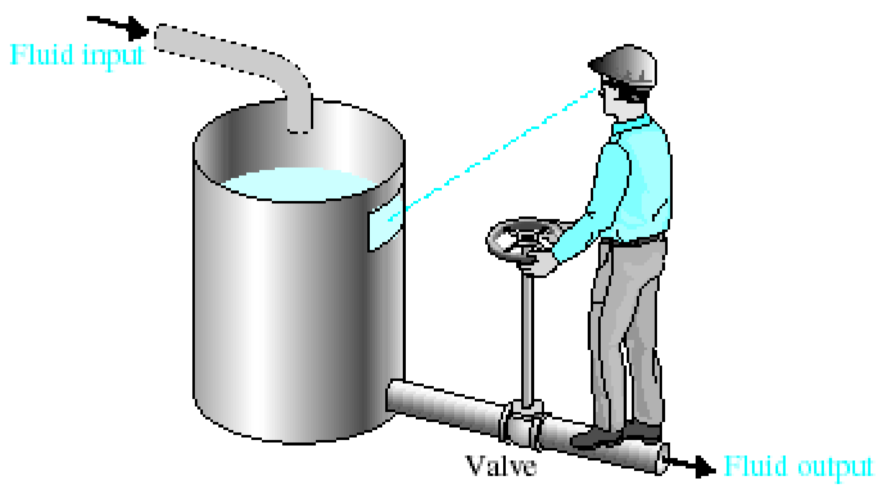
Controller is electronics, valves, etc. that control fuel flow into furnace.

Input is thermostat position

Automatic control system

Examples of Modern Control Systems

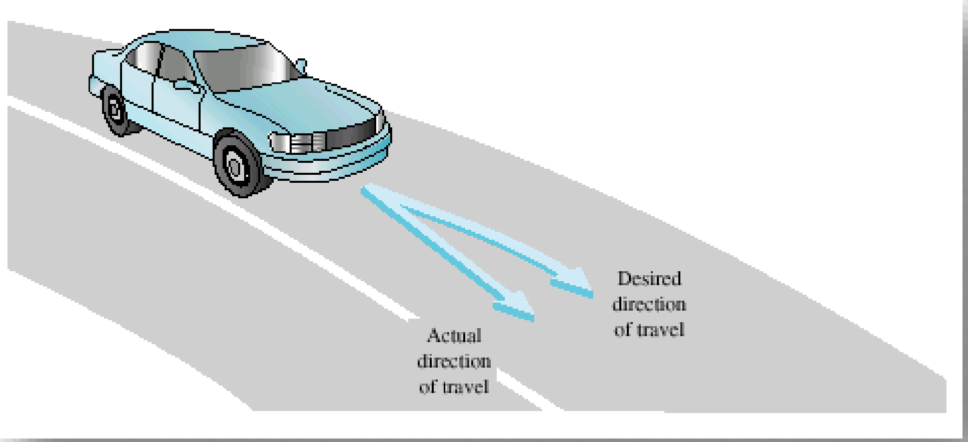
A manual control system for regulating the level of fluid in a tank by adjusting the output valve. The operator views the level of fluid through a port in the side of the tank.



Automatic control system

Transportation

Car and Driver

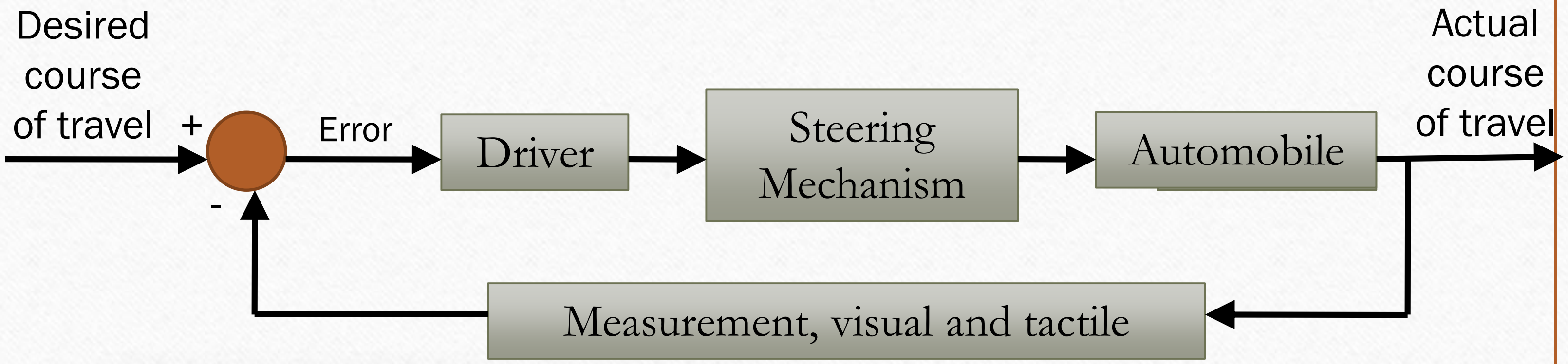


- Objective: To control direction and speed of car
- Outputs: Actual direction and speed of car
- Control inputs: Road markings and speed signs
- Disturbances: Road surface and grade, wind, obstacles
- Possible subsystems: The car alone, power steering system, breaking system

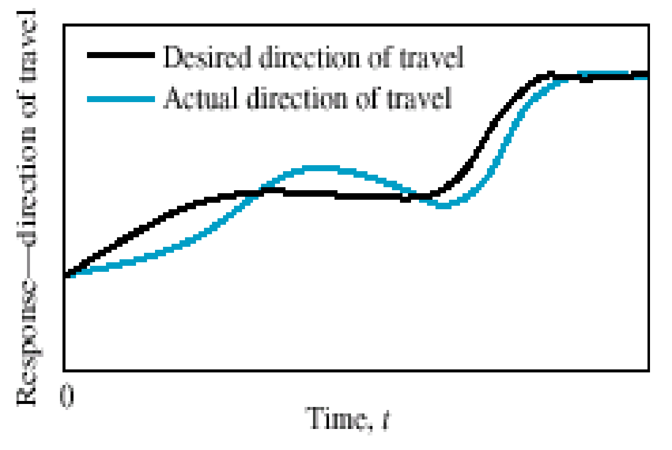
Automatic control system

Transportation

- Functional block diagram:



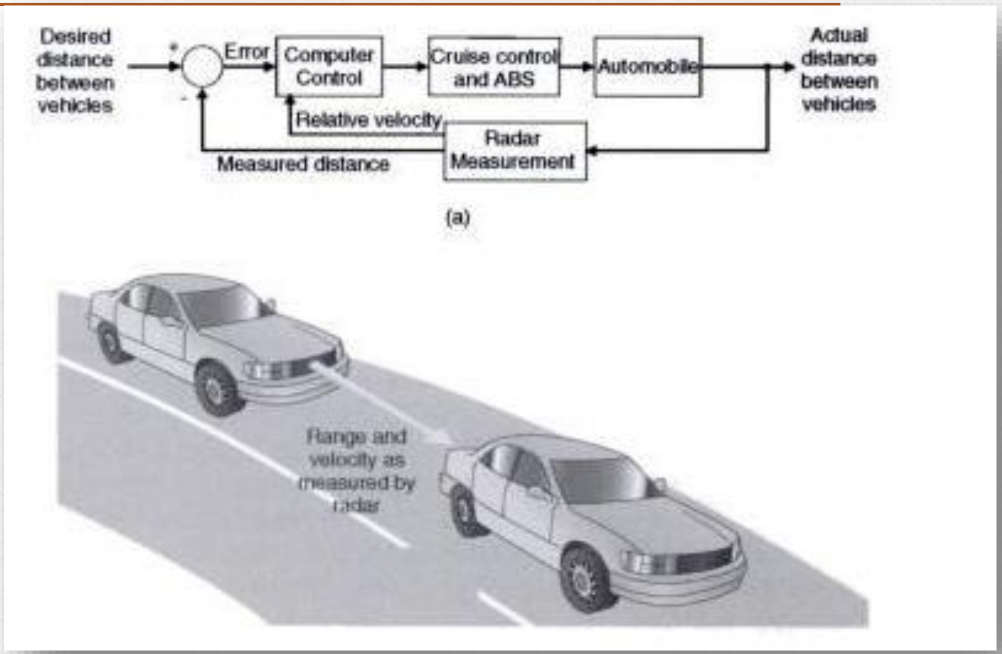
- Time response:



Automatic control system

Transportation

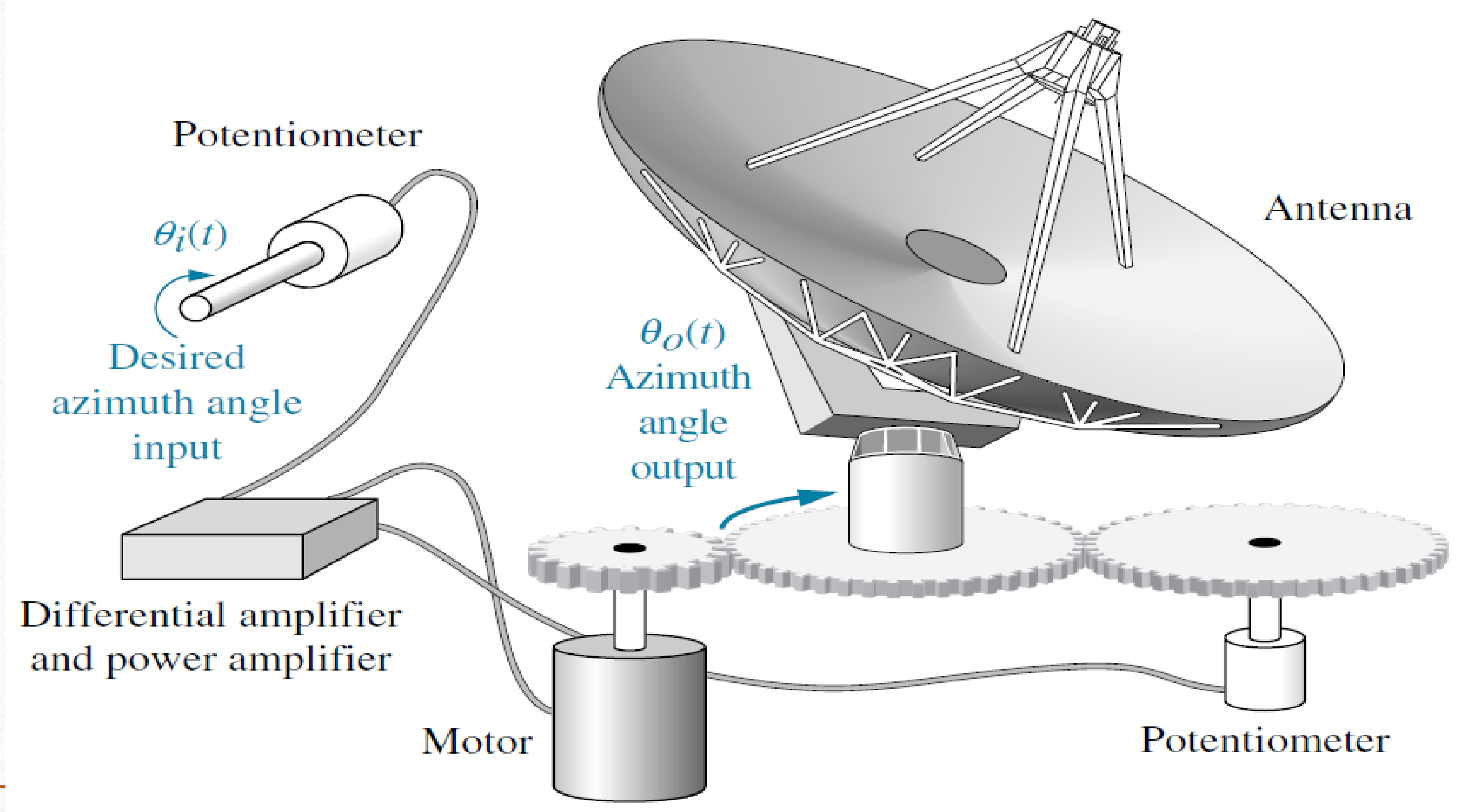
- Consider using a radar to measure distance and velocity to autonomously maintain distance between vehicles.



- Automotive: Engine regulation, active suspension, anti-lock breaking system (ABS)
- Steering of missiles, planes, aircraft and ships at sear.

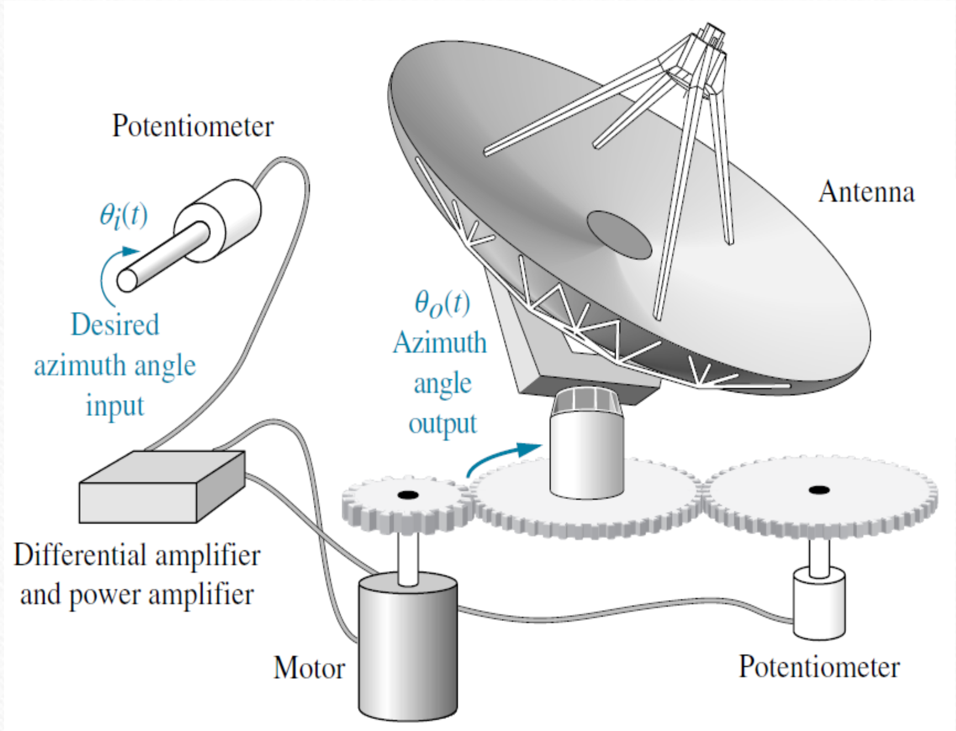
Automatic control system

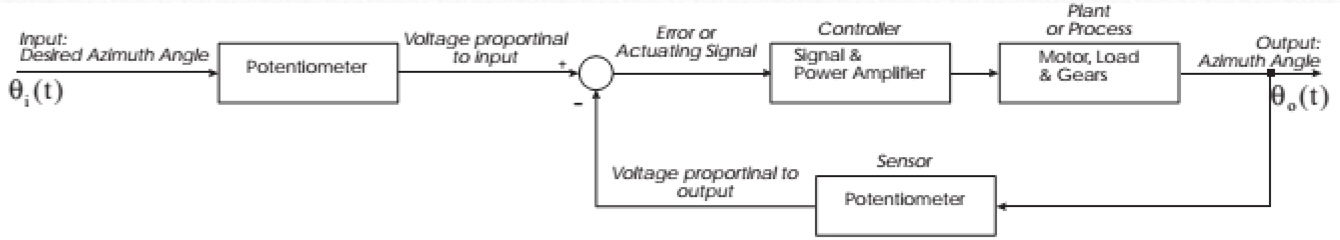
- Azimuth Position Control System Example



Automatic control system

Azimuth Position Control System Example

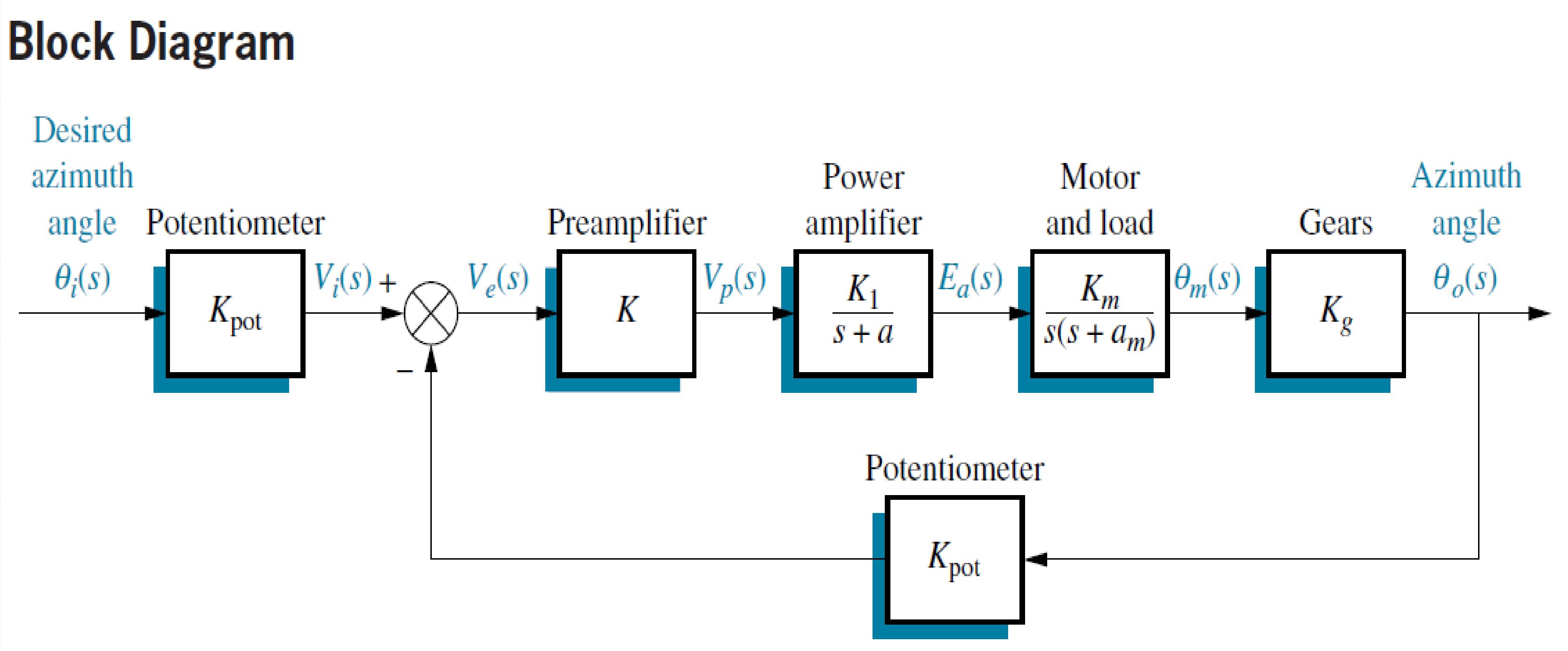




Block Schematic Diagram

Automatic control system

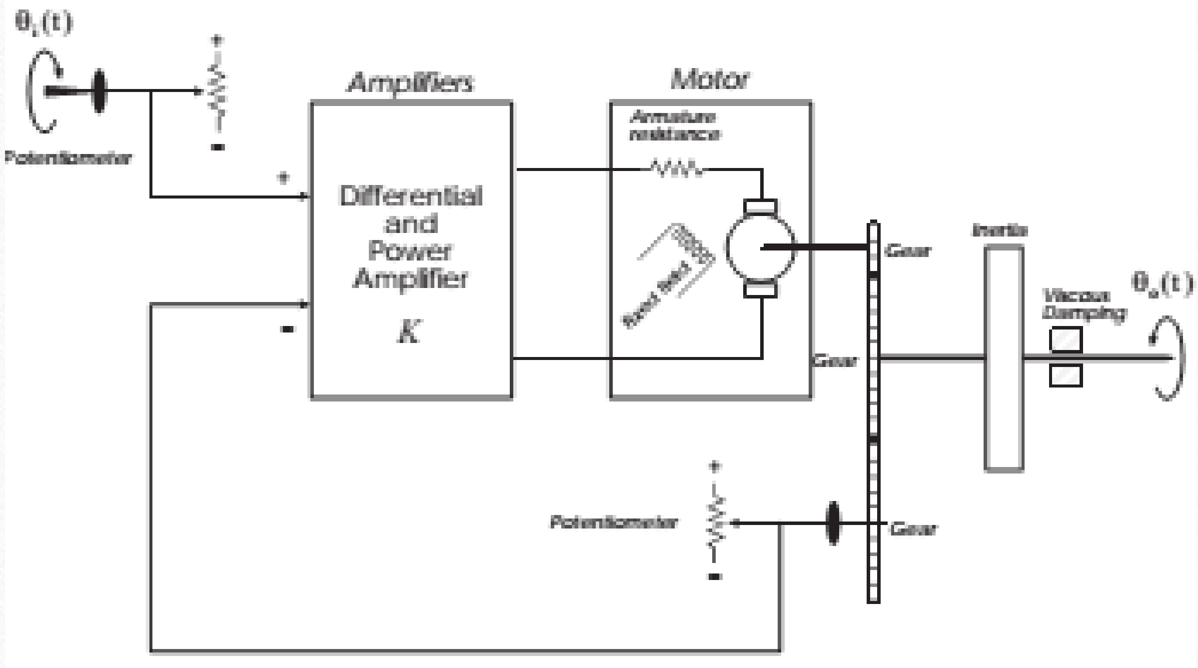
- Azimuth Position Control System Example



Automatic control system

Transform the Physical System into a Schematic

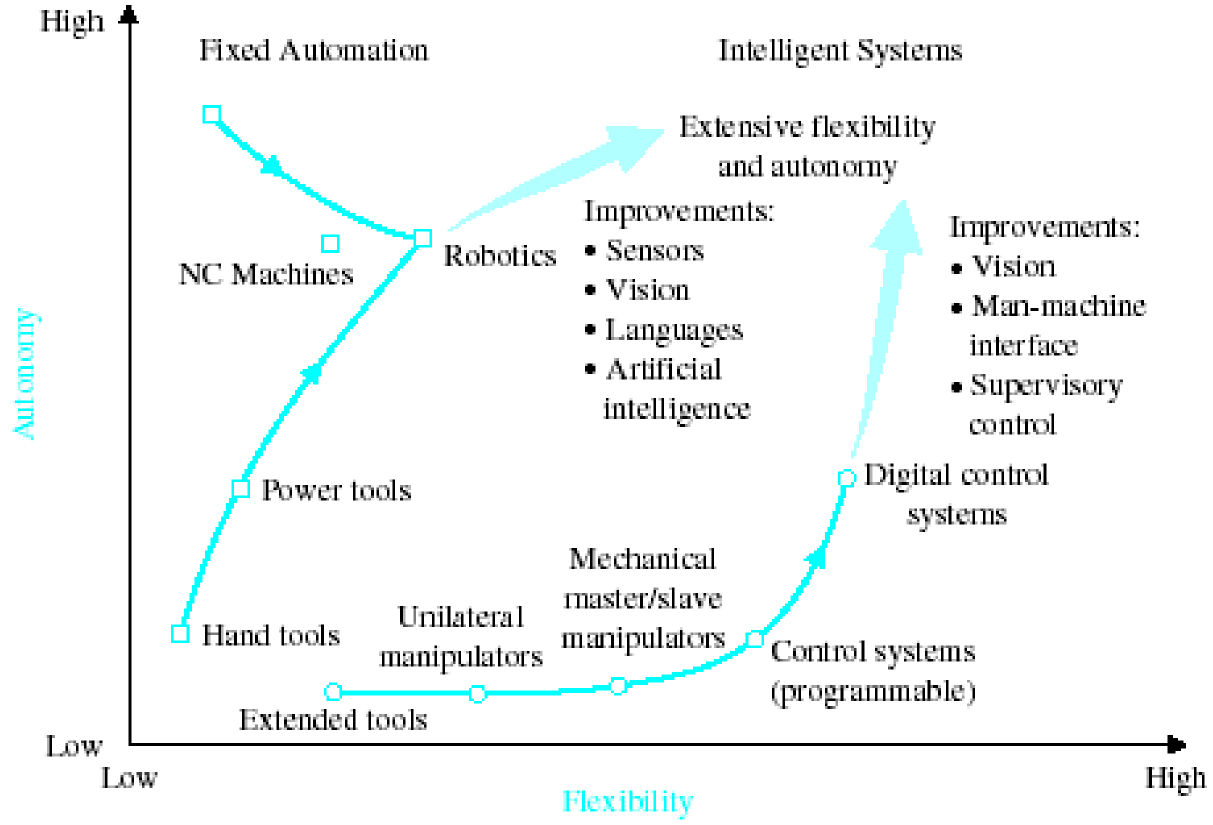
- **Makes relationships more concrete**
- **Enables decisions to be made about what can be neglected in formulating the mathematical model.**
- **Assumptions made can be easily reviewed and schematic and/or model adjusted as necessary.**
- **Should be kept as simple as possible:**
  - **Checked by analysis and simulation**
  - **Phenomena added if results do not agree with observed behavior**



Block Schematic Diagram

Automatic control system

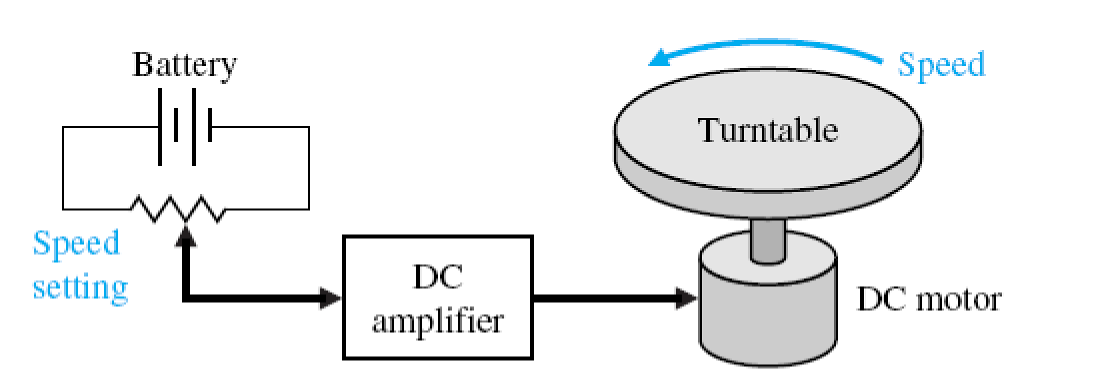
The Future of Control Systems



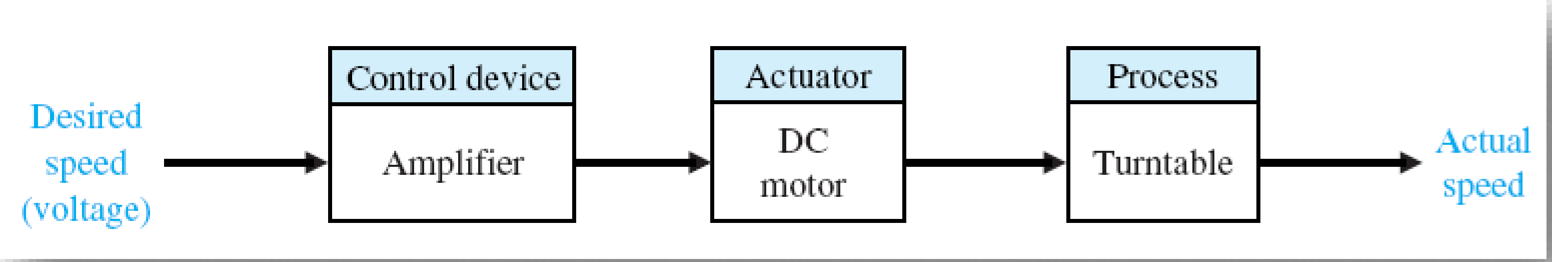
Future evolution of control systems and robotics.

Turntable Speed Control

- Application: CD player, computer disk drive
- Requirement: Constant speed of rotation
- Open loop control system:

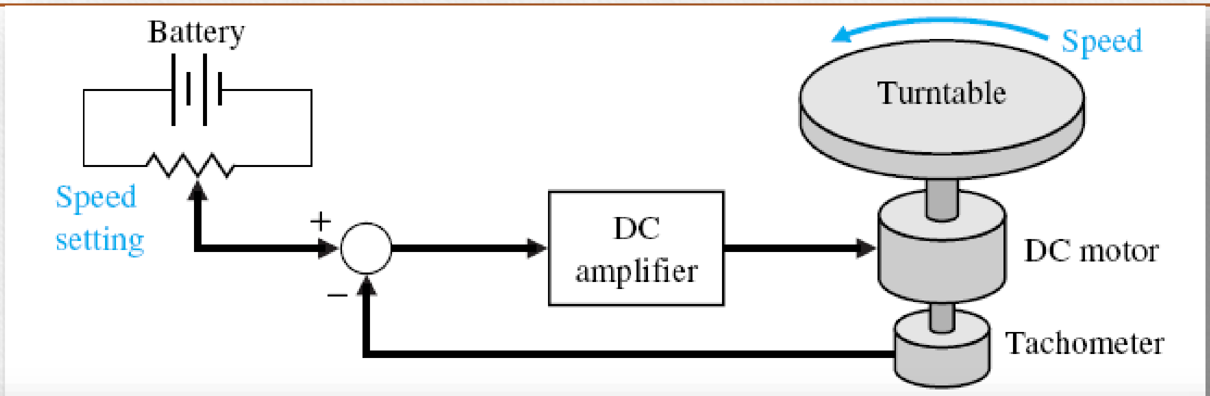


- Block diagram representation:

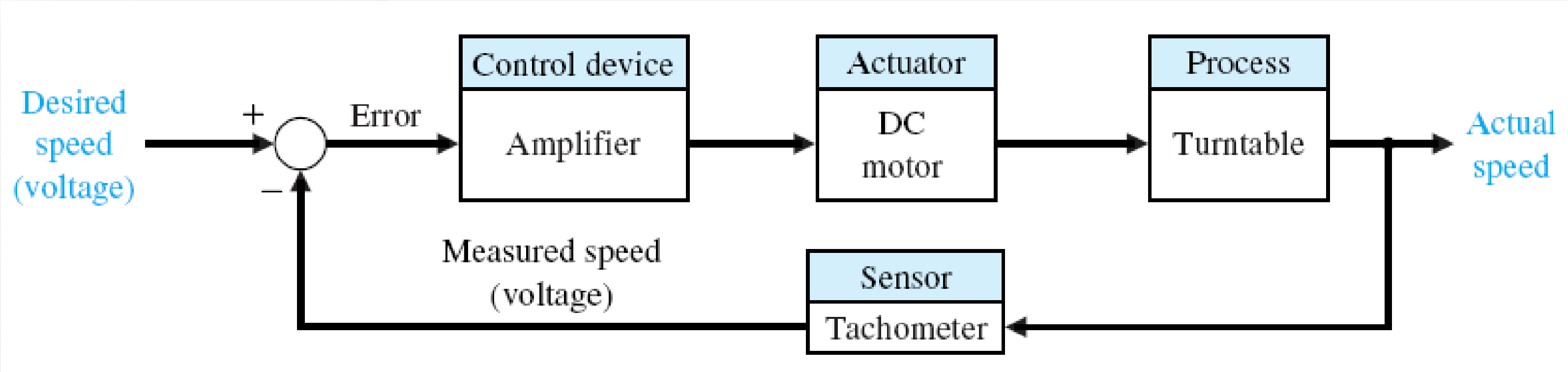


Turntable Speed Control

- Closed-loop control system:

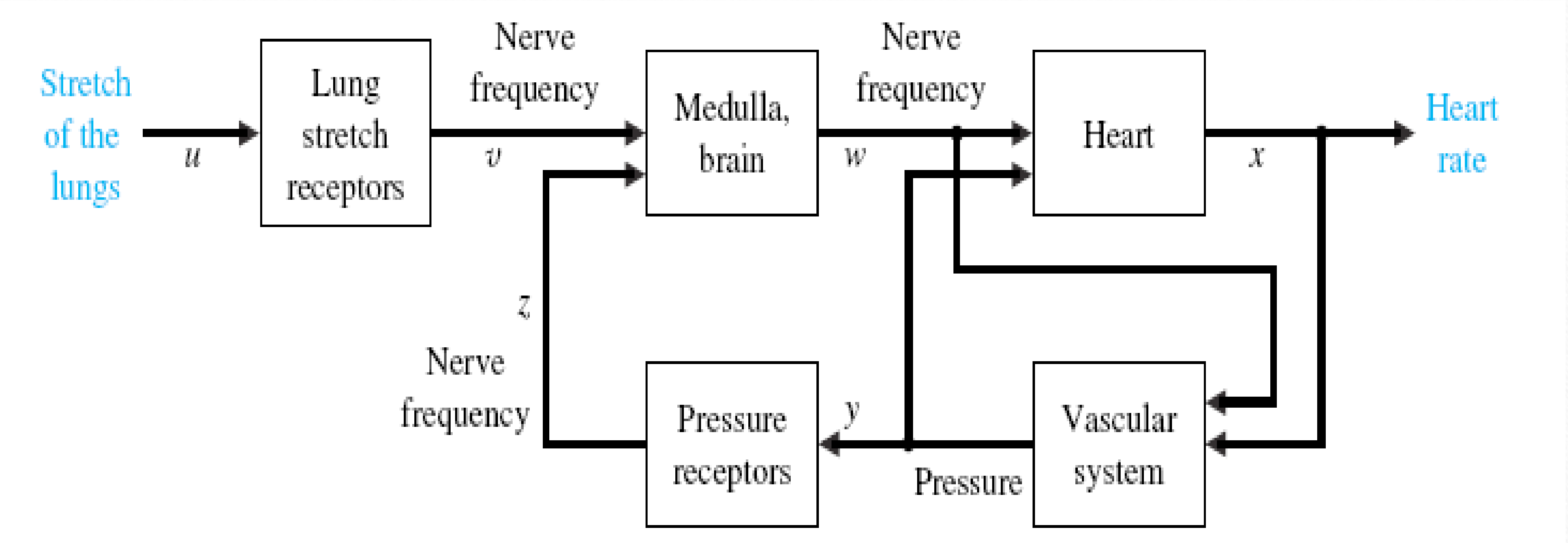


- Block diagram representation:



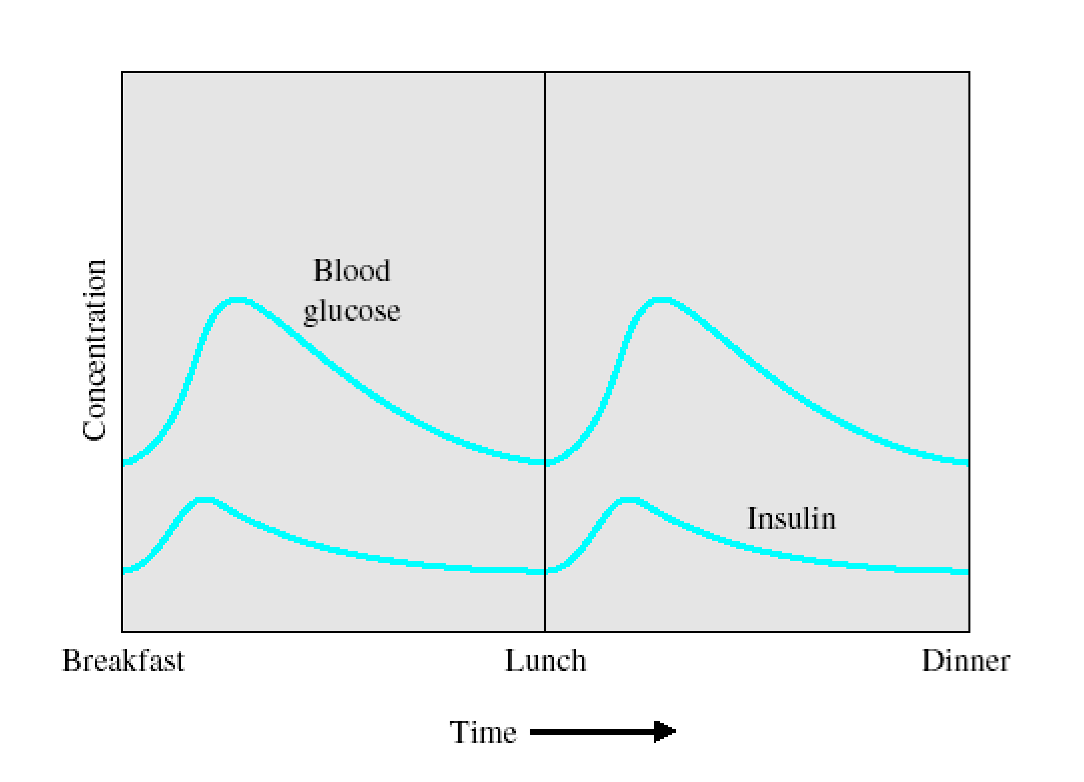
Automatic control system

Design Example



Automatic control system

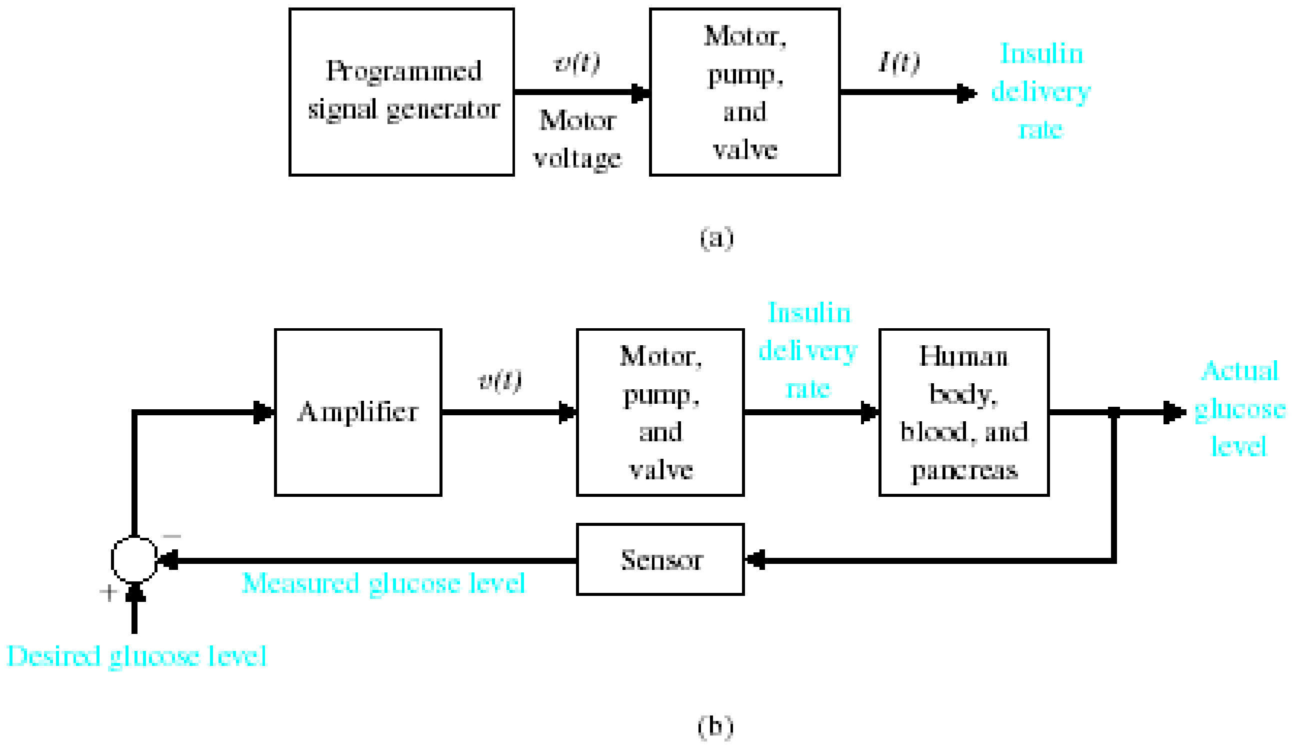
Design Example



The blood glucose and insulin levels for a healthy person.

Automatic control system

Design Example



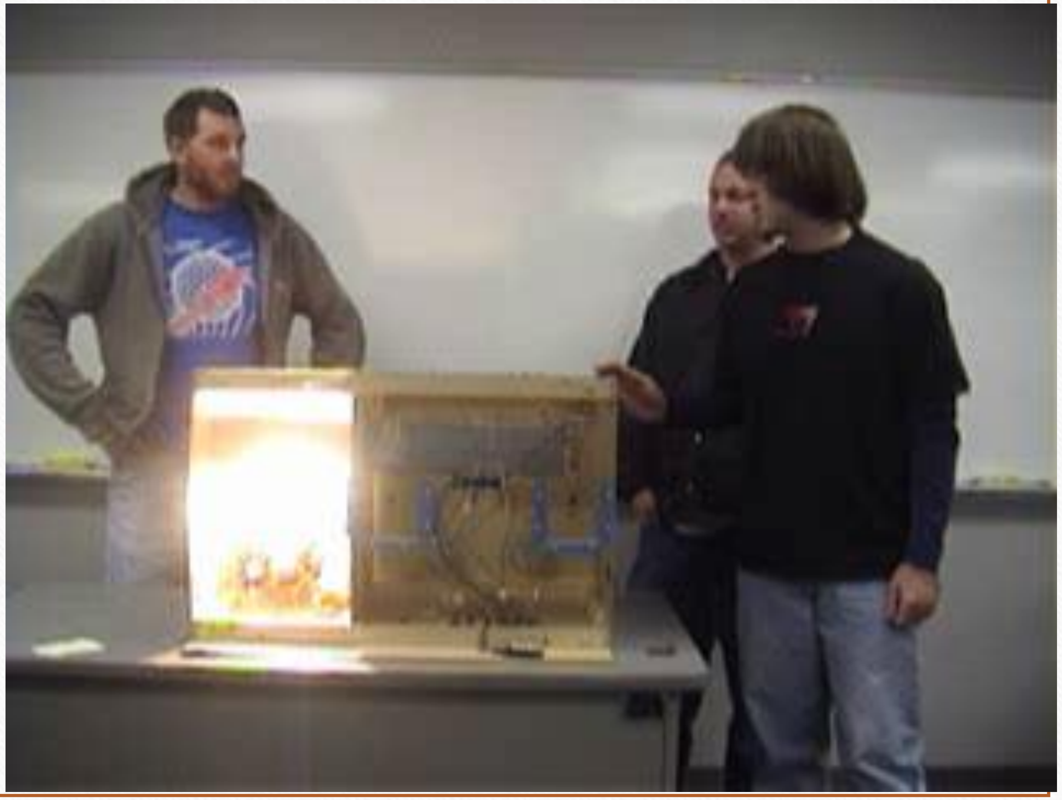
(a) Open-loop (without feedback) control and (b) closed-loop control of blood glucose.

Project Examples

Model Examples

- Car parking

- HVAC system



Appendix

Laplace transform

Automatic control system

Defination of Laplace Transform

Given a function $f(t)$, its Laplace transform, denoted by $F(s)$ or $\mathcal{L}[f(t)]$, is given by

$$\boxed{\mathcal{L}[f(t)] = F(s) = \int_{0^-}^{\infty} f(t)e^{-st}\,dt}$$

where s is a complex variable given by

$$\boxed{s = \sigma + j\omega}$$

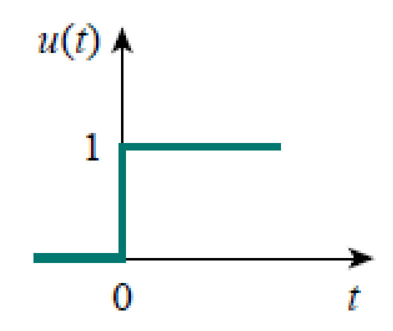
The Laplace transform is an integral transformation of a function $f(t)$ from the time domain into the complex frequency domain, giving $F(s)$.

Automatic control system

Defination of Laplace Transform

a) Step function

$$\mathcal{L}[f(t)] = F(s) = \int_{0^-}^{\infty} f(t)e^{-st}\, dt$$



$$\mathcal{L}[u(t)] = \int_{0^-}^{\infty} 1e^{-st}\, dt = -\frac{1}{s}e^{-st}\Big|_{0}^{\infty} = -\frac{1}{s}(0) + \frac{1}{s}(1) = \frac{1}{s}$$

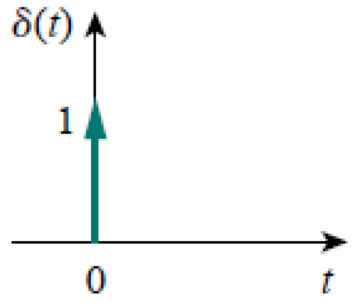
Automatic control system

Defination of Laplace Transform

b) Impulse function

$$\mathcal{L}[\delta(t)] = \int_{0^-}^{\infty} \delta(t) e^{-st}\, dt$$

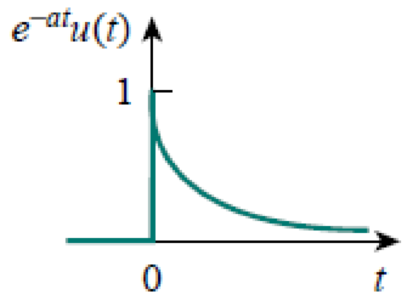
$$= e^{-0} = 1$$



c) Exponential function

$$\mathcal{L}[e^{-at}u(t)] = \int_{0^-}^{\infty} e^{-at} e^{-st}\, dt$$

$$= -\frac{1}{s+a} e^{-(s+a)t} \Big|_{0}^{\infty} = \frac{1}{s+a}$$



Automatic control system

Defination of Laplace Transform

Example

Determine the Laplace transform of $f(t) = \sin \omega t u(t)$.

Solution

$$F(s) = \mathcal{L}[\sin \omega t] = \int_0^\infty \underbrace{(\sin \omega t)}e^{-st}\,dt$$

$$= \int_0^\infty \left(\frac{e^{j\omega t} - e^{-j\omega t}}{2j}\right) e^{-st}\,dt$$

$$= \frac{1}{2j}\int_0^\infty (e^{-(s-j\omega)t} - e^{-(s+j\omega)t})\,dt = \frac{1}{2j}\left(\frac{1}{s-j\omega} - \frac{1}{s+j\omega}\right) = \frac{\omega}{s^2+\omega^2}$$

Automatic control system

Propereties of Laplace Transform

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Automatic control system

Properetios of Laplace Transform

Time Shift

If $F(s)$ is the Laplace transform of $f(t)$, then

$$\mathcal{L}[f(t-a)u(t-a)] = \int_0^\infty f(t-a)u(t-a)e^{-st}\,dt \qquad a \geq 0$$

$$\begin{cases} u(t-a) = 0 & t < a \\ u(t-a) = 1 & t > a \end{cases}$$

Automatic control system

Properetiеs of Laplace Transform

Time Shift

$$\mathcal{L}[f(t-a)u(t-a)] = \int_a^{\infty} f(t-a)e^{-st}\,dt$$

If we let $x = t - a$, then $dx = dt$ and $t = x + a$.

$$\mathcal{L}[f(t-a)u(t-a)] = \int_0^{\infty} f(x)e^{-s(x+a)}\,dx$$

$$= e^{-as}\int_0^{\infty} f(x)e^{-sx}\,dx$$

$$= e^{-as}F(s)$$

$$\boxed{\mathcal{L}[f(t-a)u(t-a)] = e^{-as}F(s)}$$

Automatic control system

Propereties of Laplace Transform

Time Differentiation

$$\mathcal{L}\left[\frac{df}{dt}\right] = \int_{0^-}^{\infty} \frac{df}{dt} e^{-st}\, dt$$

$$\boxed{\mathcal{L}[f'(t)] = sF(s) - f(0^-)}$$

Automatic control system

Propereties of Laplace Transform

Time Differentiation

$$\mathcal{L}\left[\frac{d^2 f}{dt^2}\right] = s^2 F(s) - sf(0^-) - f'(0^-)$$

$$\boxed{\mathcal{L}\left[\frac{d^n f}{dt^n}\right] = s^n F(s) - s^{n-1} f(0^-) - s^{n-2} f'(0^-) - \cdots - s^0 f^{(n-1)}(0^-)}$$

Automatic control system

Properetíes of Laplace Transform

Time Integration

$$\mathcal{L}\left[\int_0^t f(t)\,dt\right] = \int_{0-}^{\infty}\left[\int_0^t f(x)\,dx\right]e^{-st}\,dt$$

$$\boxed{\mathcal{L}\left[\int_0^t f(t)\,dt\right] = \frac{1}{s}F(s)}$$

Automatic control system

Propereties of Laplace Transform

Time Integration

As an example, if we let $f(t) = u(t)$, $F(s) = 1/s$

$$\mathcal{L}\left[\int_0^t f(t)\,dt\right] = \mathcal{L}[t] = \frac{1}{s}\left(\frac{1}{s}\right)$$

$$\mathcal{L}\left[\int_0^t t\,dt\right] = \mathcal{L}\left[\frac{t^2}{2}\right] = \frac{1}{s}\frac{1}{s^2}$$

$$\mathcal{L}[t] = \frac{1}{s^2}$$

$$\mathcal{L}[t^2] = \frac{2}{s^3}$$

$$\boxed{\mathcal{L}[t^n] = \frac{n!}{s^{n+1}}}$$

Automatic control system

Properetiess of Laplace Transform

Initial and Final Values

$$f(0^+) = \lim_{s\to\infty} sF(s)$$

For an example;

$$f(t) = e^{-2t}\cos 10t \quad \Longleftrightarrow \quad F(s) = \frac{s+2}{(s+2)^2+10^2}$$

Then;

$$f(0^+) = \lim_{s\to\infty} sF(s) = \lim_{s\to\infty} \frac{s^2+2s}{s^2+4s+104}$$

$$= \lim_{s\to\infty} \frac{1+2/s}{1+4/s+104/s^2} = 1$$

Laplace transform

Functions

- Substitutes relatively more easily solved algebraic equations for relatively more difficult to solve differential equations

TIME DOMAIN		FREQUENCY DOMAIN
$\delta(t)$	unit impulse	1
A	step	$\frac{A}{s}$
t	ramp	$\frac{1}{s^2}$
t^2		$\frac{2}{s^3}$
$t^n,\ n > 0$		$\frac{n!}{s^{n+1}}$
e^{-at}	exponential decay	$\frac{1}{s+a}$
$\sin(\omega t)$		$\frac{\omega}{s^2+\omega^2}$
$\cos(\omega t)$		$\frac{s}{s^2+\omega^2}$
te^{-at}		$\frac{1}{(s+a)^2}$
t^2e^{-at}		$\frac{2!}{(s+a)^3}$