

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	11-2	Introduction Syllable/Course specs Control system classifications Laplace transform			Ref-01		Dr. Mostafa Elsayed
2	18-2	Modeling - Mechanical system - Hydraulic system	Project idea and team names	DC-Motor control			
3	25-2	Modeling - Electrical system (motors and combined systems)	Quiz			5/3 quizzes	
4	3-3	Block diagram Transfer function and State space		Electrical-mechanical analogy			
5	10-3	Time Response (1 st and 2 nd order)	Quiz			5/3 quizzes	
6	17-3	Steady state Error Stability analysis	Progress report	Filters			
7	24-3	Midterm					

Course plan

week	Date	Contents	Requirements	Laboratory	References	Marks	Instructor
8	31-3	Frequency Response Nyquist plot	Reports (smart building)	DC- motor Kit	Ref-01	5	Dr. Mohamed Saber Sokar
9	7-4	Frequency Response Bode Plot	Quiz	Operational amplifier circuits		5/3 quizzes	
10	14-4	Design Controller and system compensation			Ref-02		
11	21-4	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 & Quiz	5		
TOTAL		30	70	100

Projects

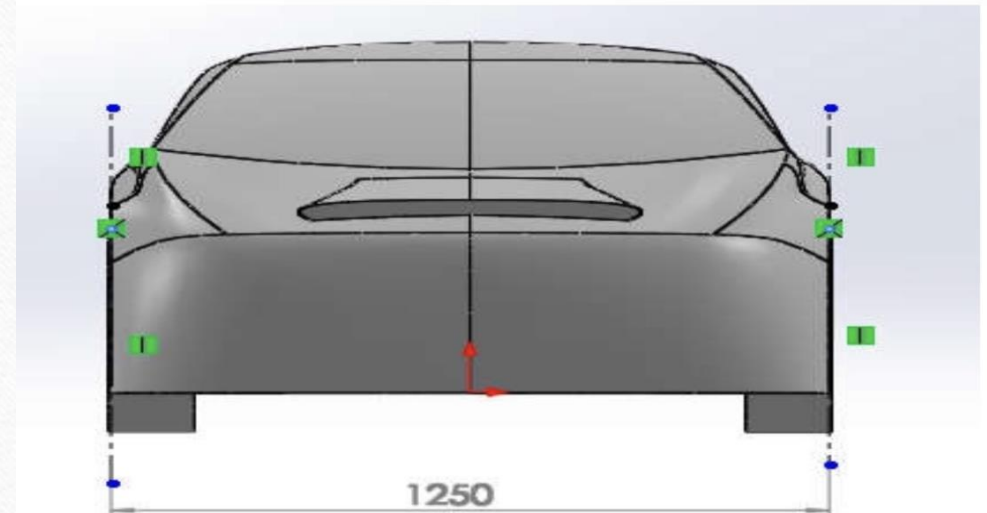
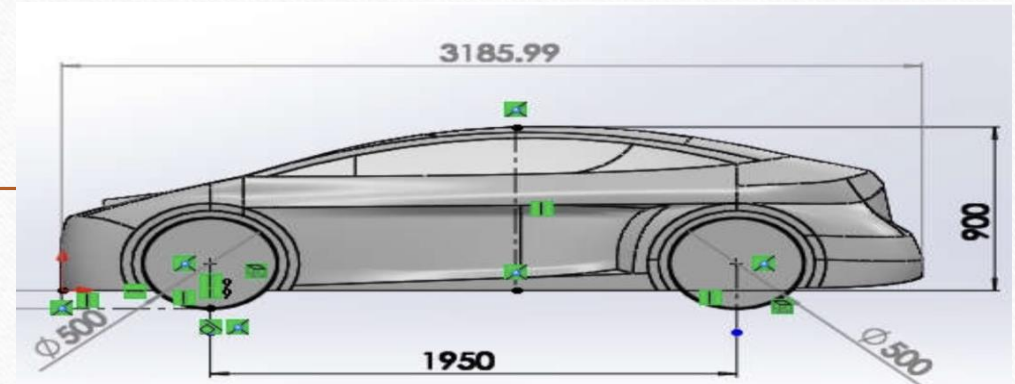
- **Electric Vehicle Control**

- **Real and Prototype Mechanisms**

- Theory of machine
- Machine design

- **Design and Manufacturing procedure**

- Steering Mechanism
- Suspension Mechanism
- Braking Mechanism



Projects

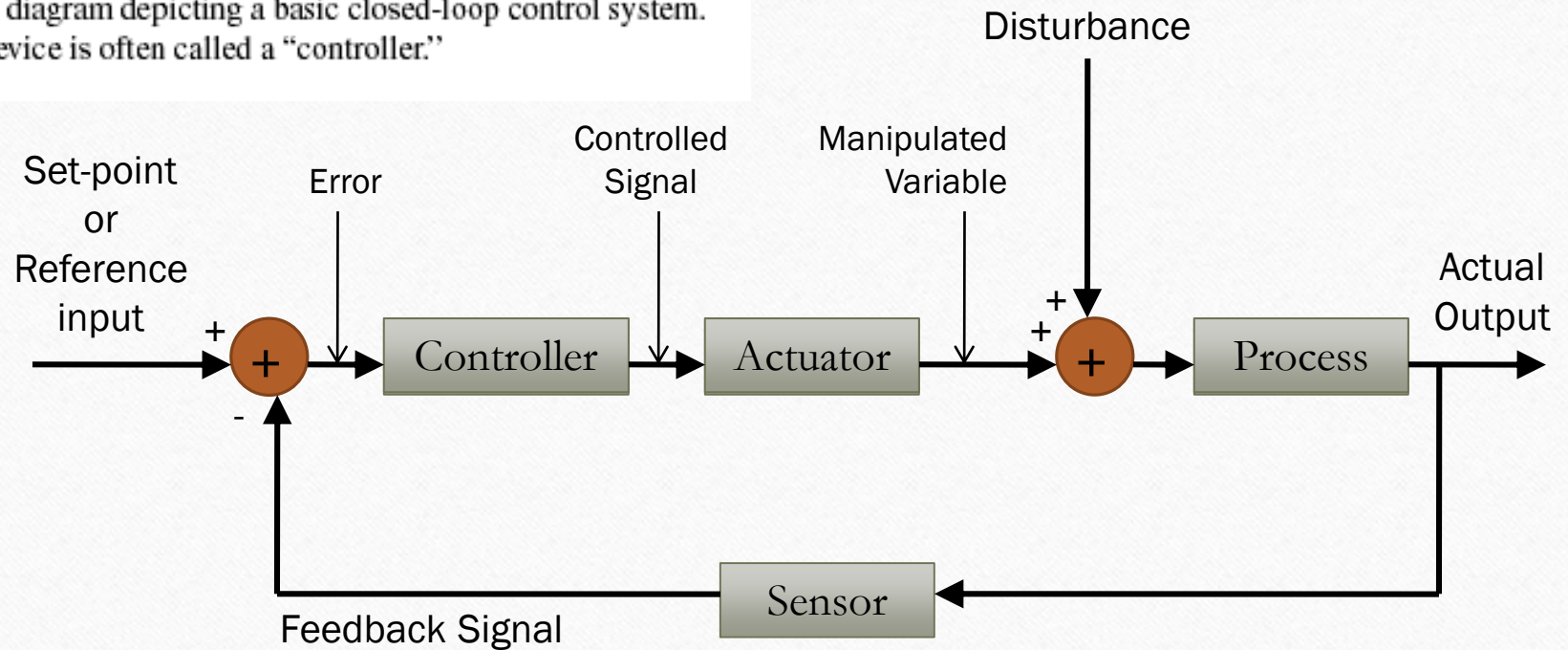
Speed	The maximum speed 140km/h, Within the city 80 km/h
shape	<ul style="list-style-type: none">- Lightweight materials used to increase energy efficiency with safety considerations.- A distinctive modern exterior.- It is robust and passes the Crash test .- The local component more than 50%.- Providing the salon with technological features to satisfy the customer and achieve competition.
Capacity	5 person
Battery	<ul style="list-style-type: none">- Power consumption of 90% AC power.- Electric motor.- The capacity of the batteries is not less than 20 kWh.- The distance to the vehicle should not be less than 200 km.- Batteries with high storage efficiency of more than 100 W / h / kg.- Big virtual life exceeds 7 years.

Automatic Control

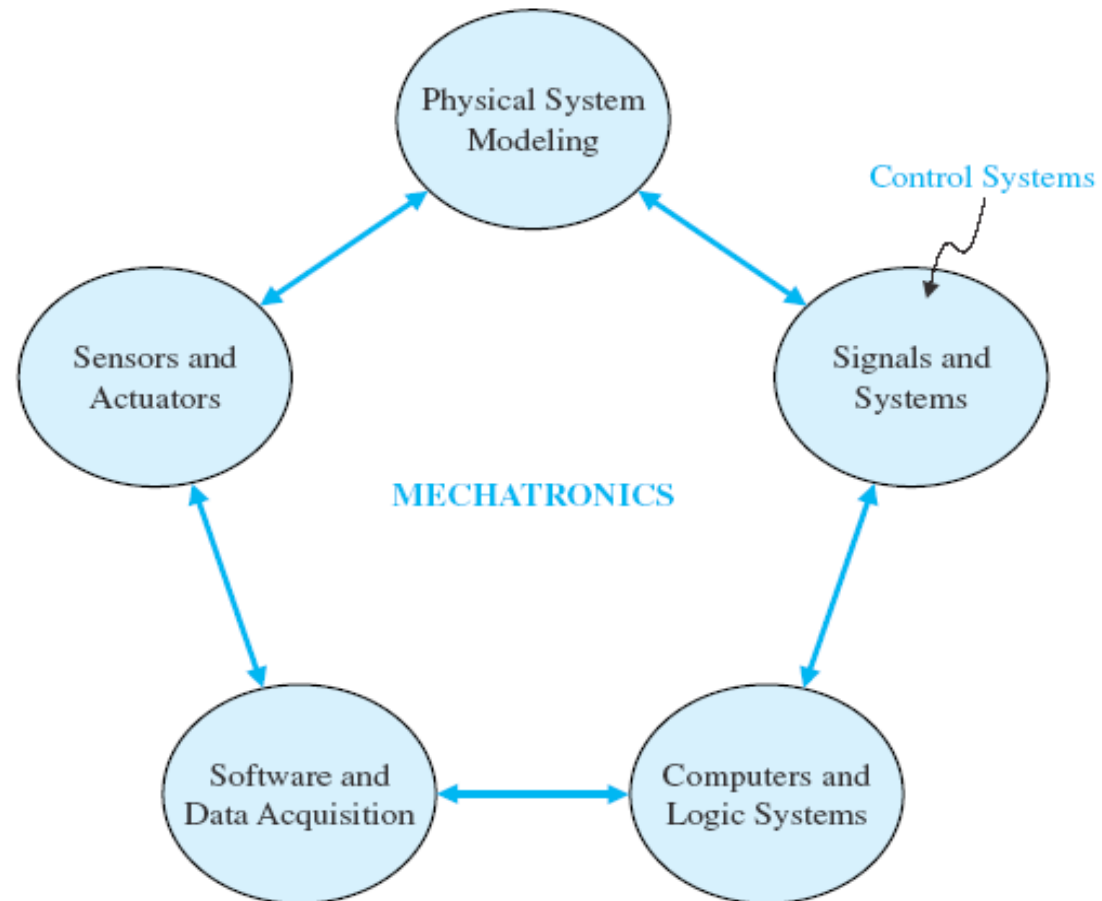
- **Lecture aims:**
 - Understand a definition of a control system
 - Facilitate combining and manipulating differential equations

Automatic control system

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

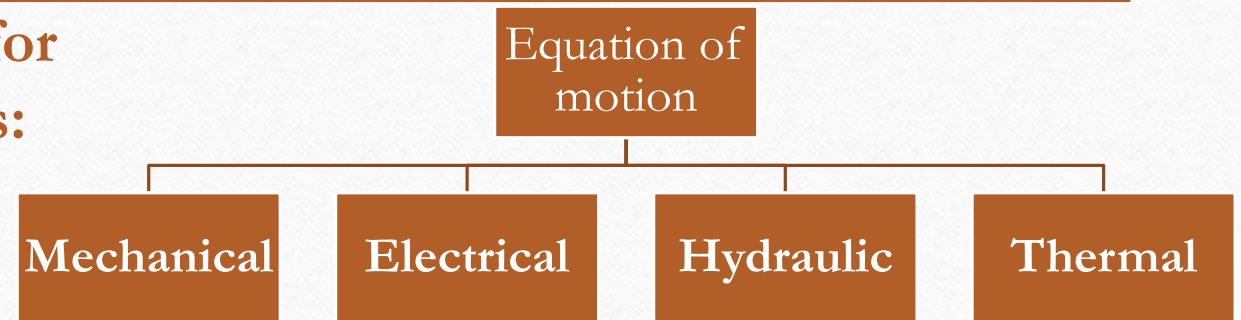


Automatic control system

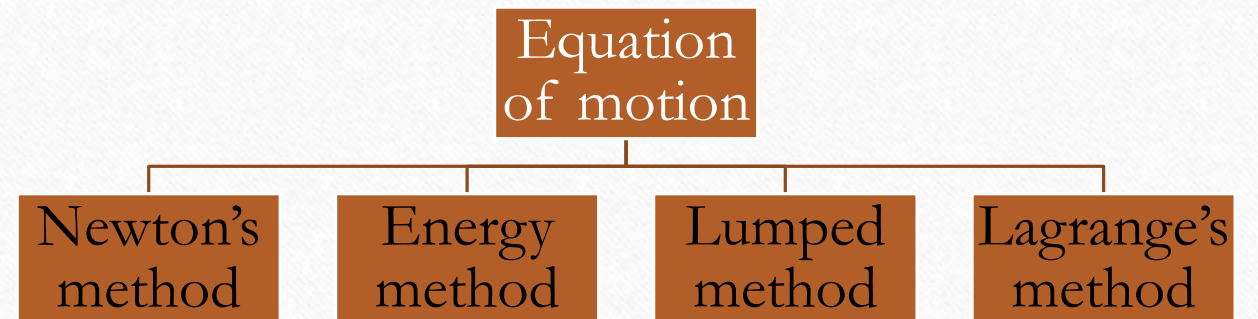


Automatic control system

Must have fundamental method for modelling many physical systems:



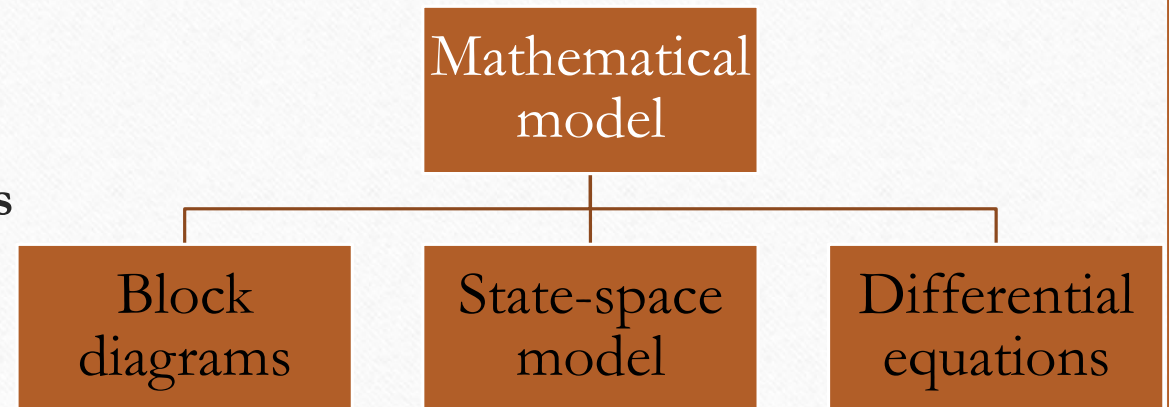
Must have fundamental method for modelling many physical systems:



Automatic control system

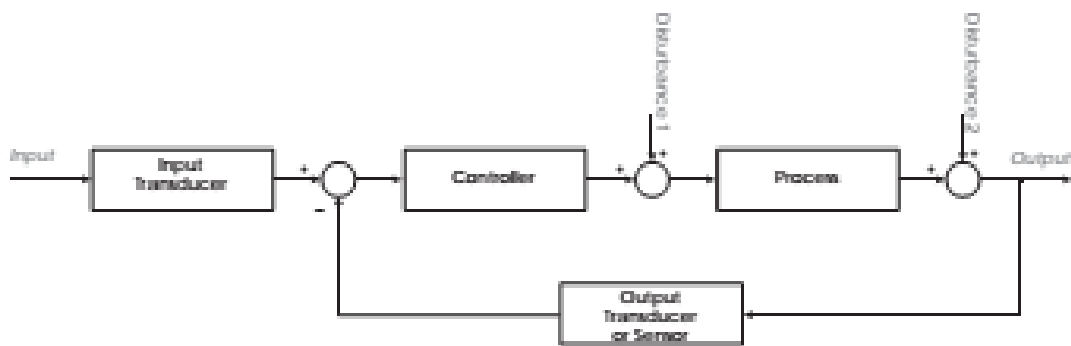
Mathematical Models for the Schematic

- 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

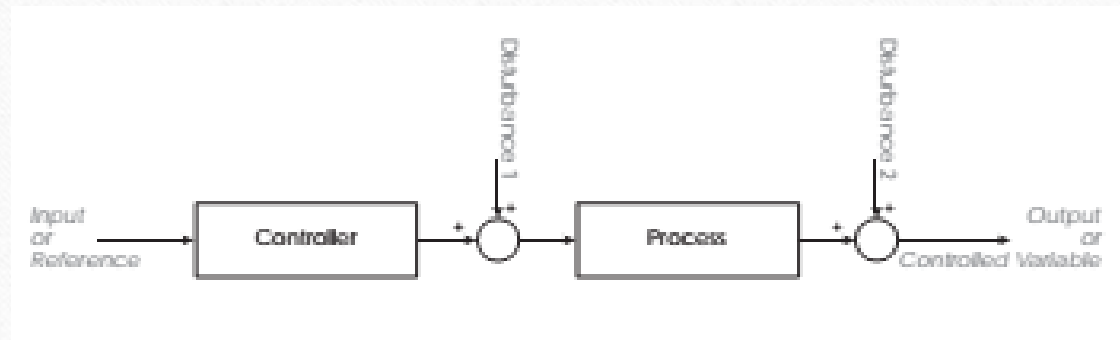


Input temperature dial position converted into a voltage by a potentiometer.

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.

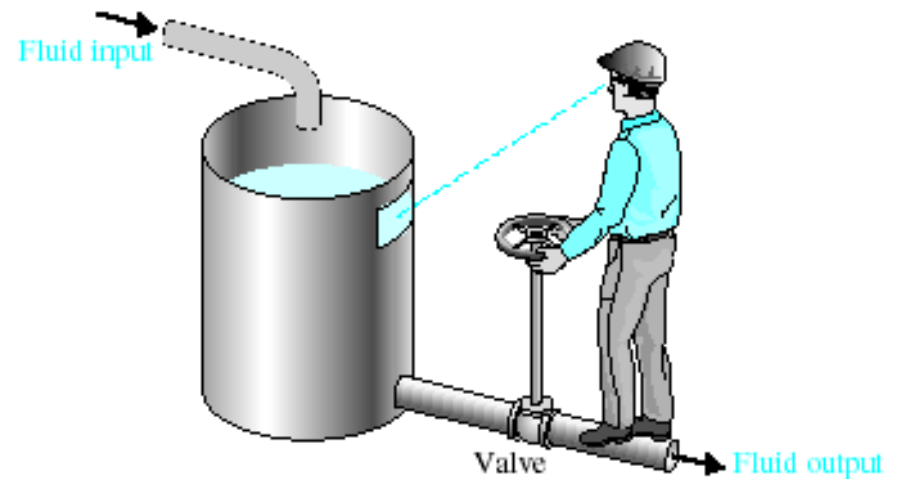
Controller is electronics, valves, etc. that control fuel flow into furnace.

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.

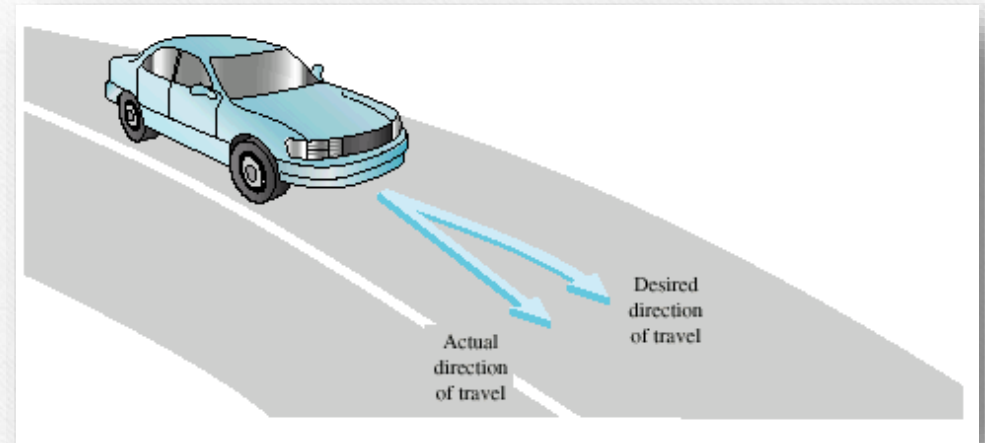


Automatic control system

Transportation

Car and Driver

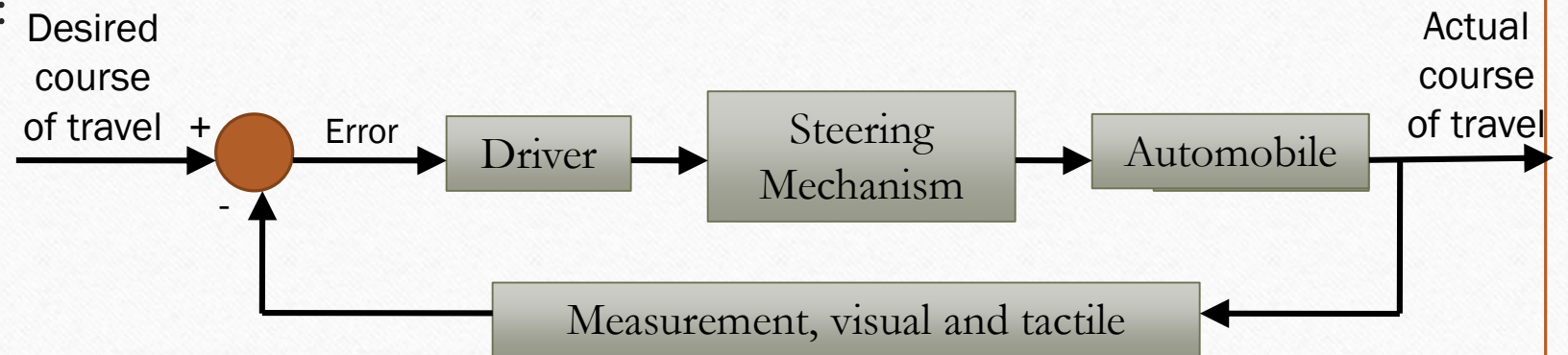
- Objective: **To control direction and speed of car**
- Outputs: **Actual direction and speed of car**
- Control inputs: **Road markings and speed signs**
- Disturbances: **Road surface and grade, wind, obstacles**
- Possible subsystems: **The car alone, power steering system, breaking system**



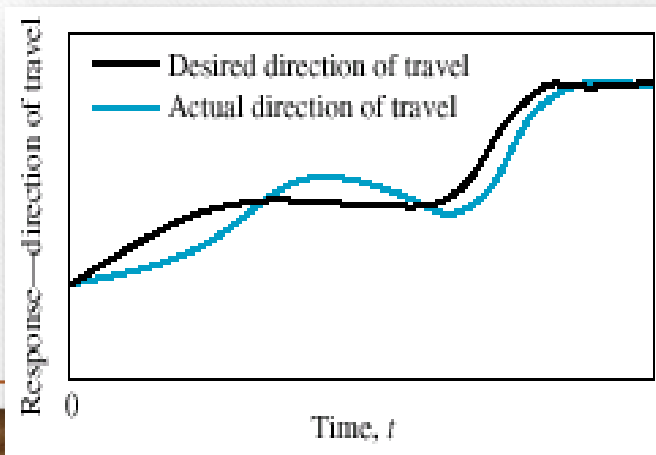
Automatic control system

Transportation

- Functional block diagram:



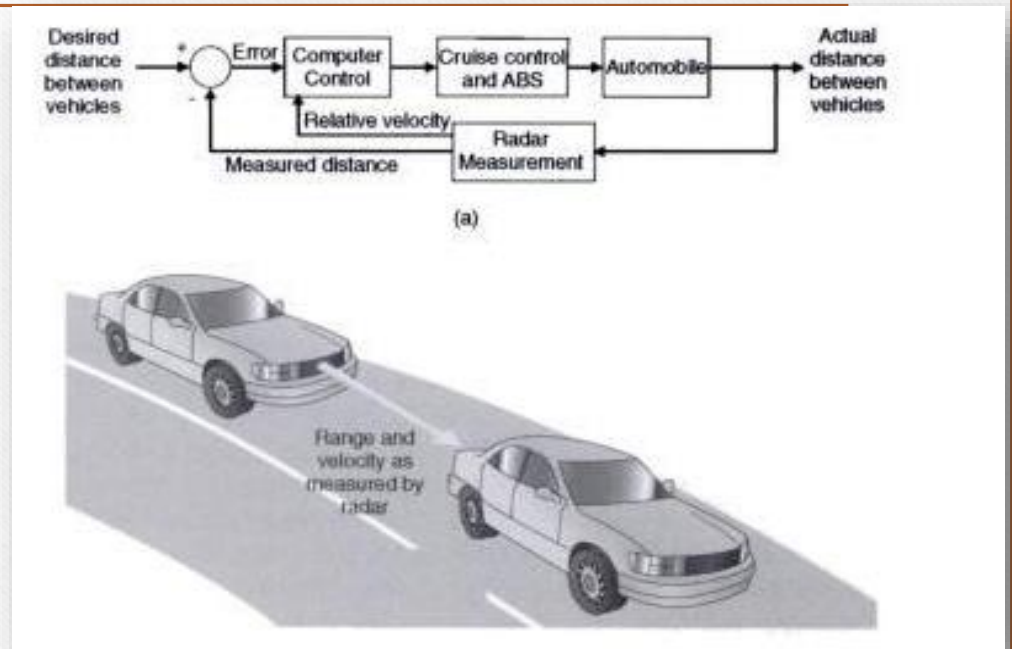
- Time response:



Automatic control system

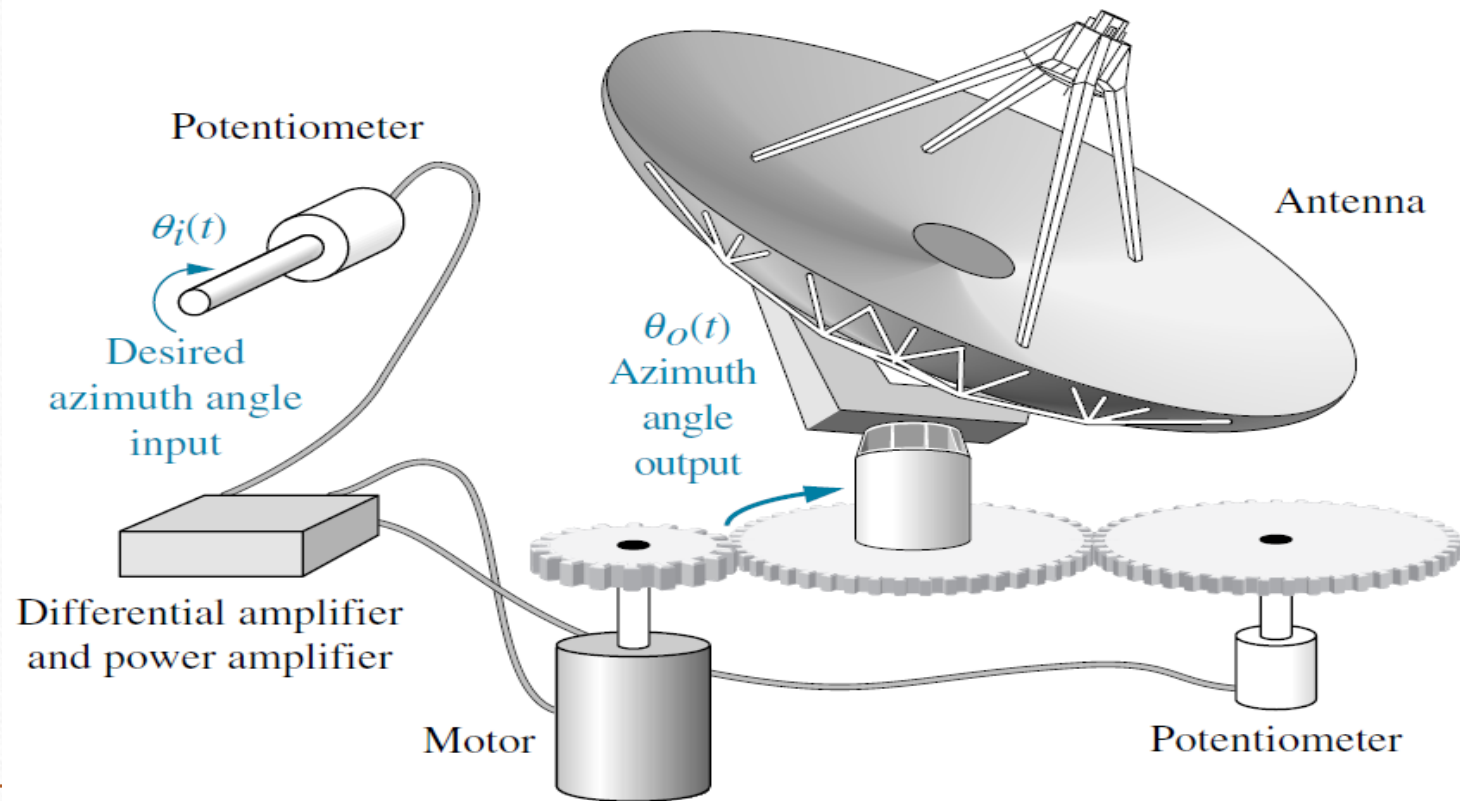
Transportation

- 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 sea.



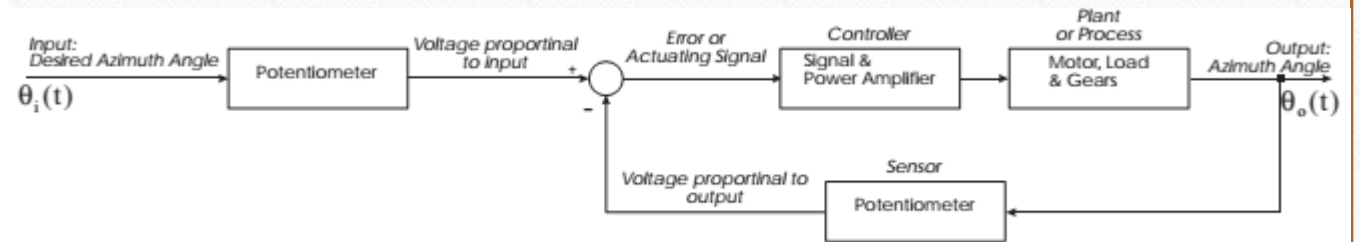
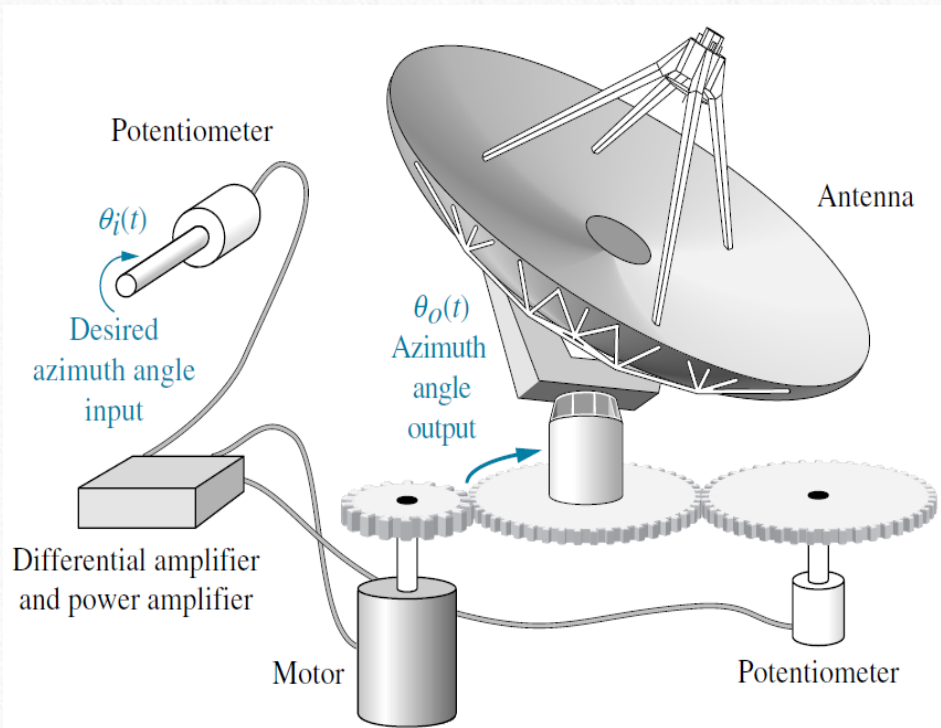
Automatic control system

- Azimuth Position Control System Example



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Azimuth Position Control System Example

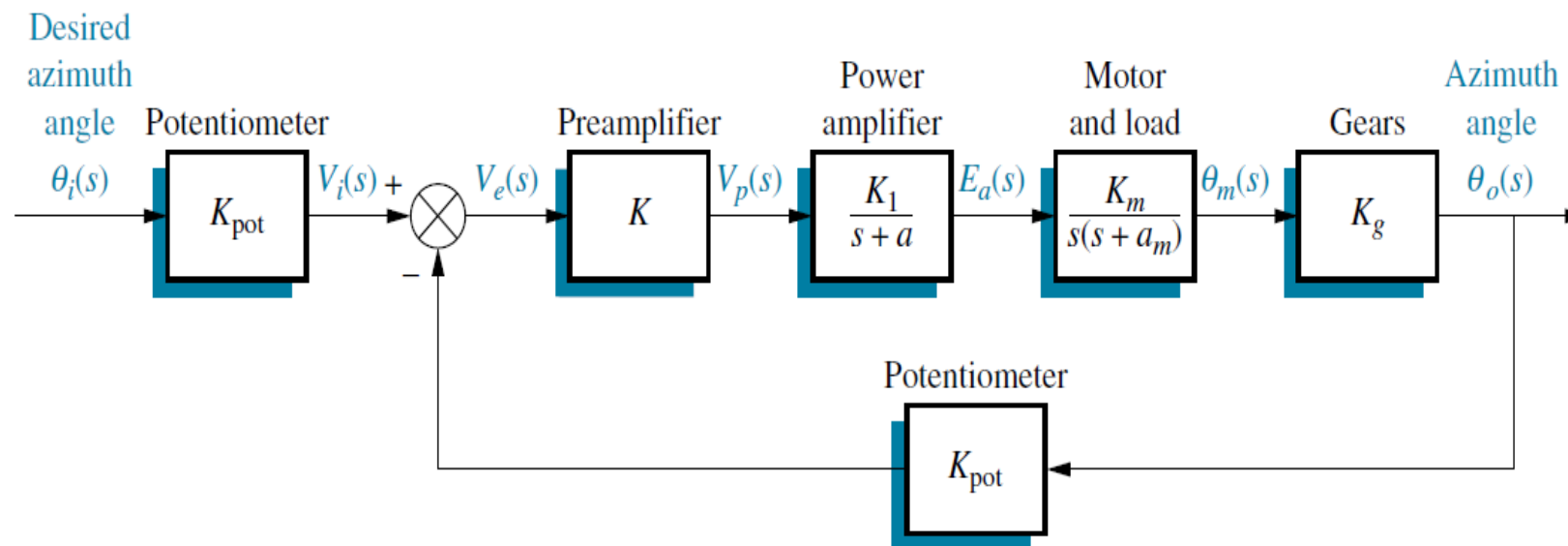


Block Schematic Diagram

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- Azimuth Position Control System Example

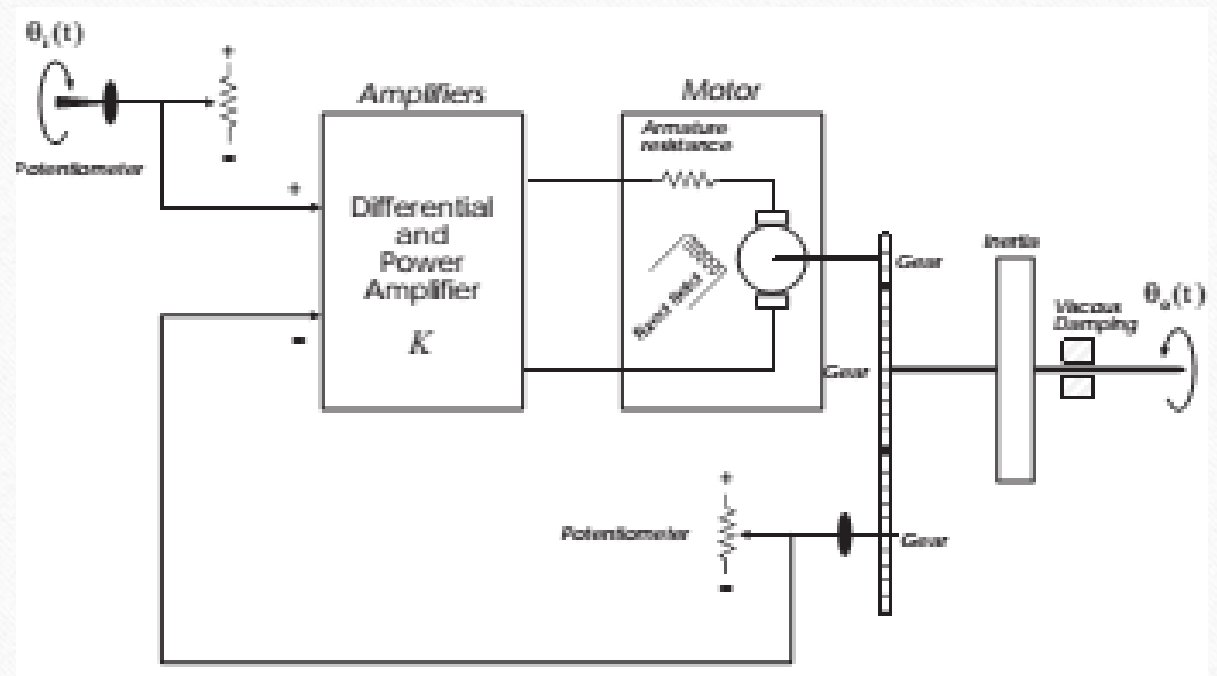
Block Diagram



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

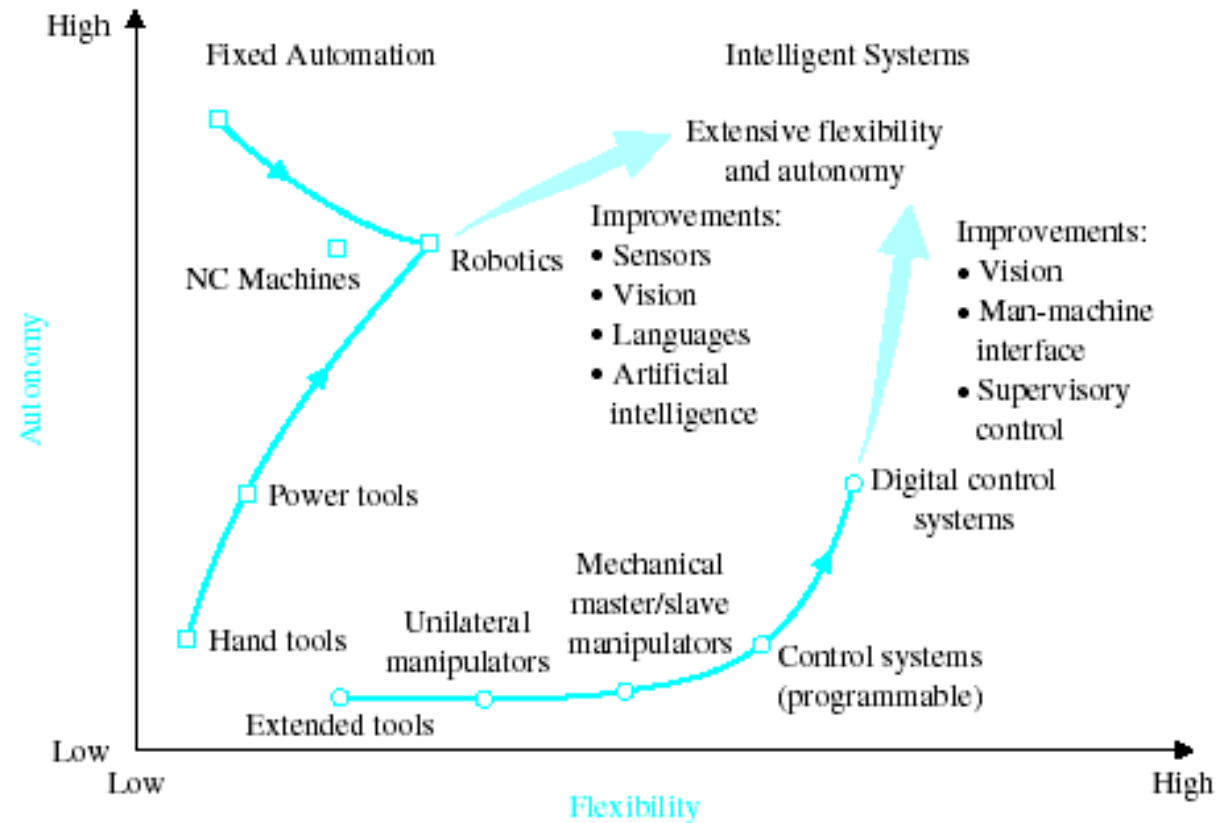


Block Schematic Diagram

Automatic control system

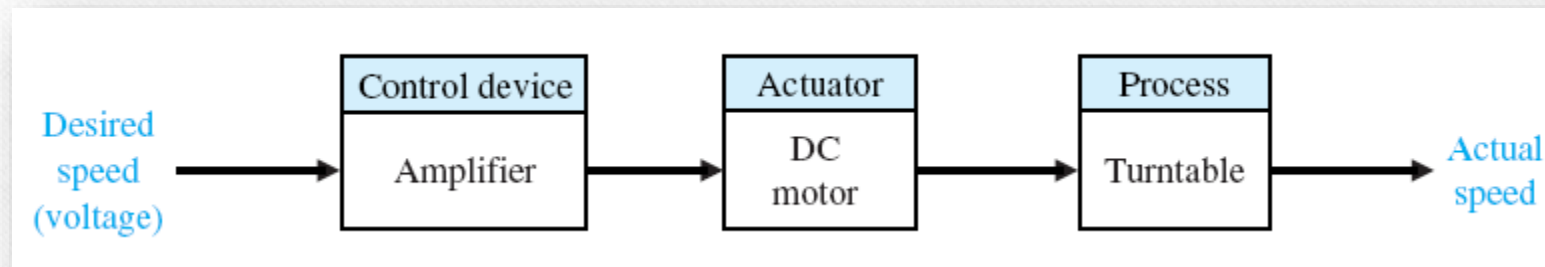
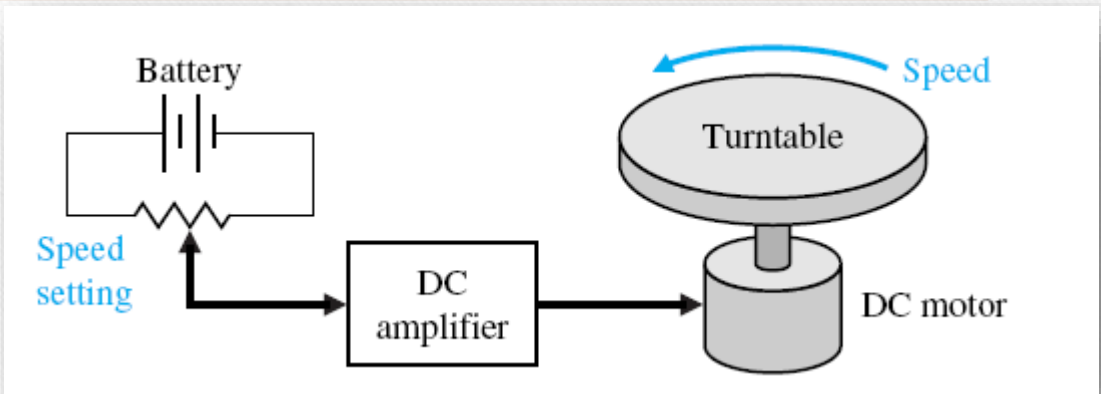
The Future of Control Systems

Future evolution of control systems and robotics.



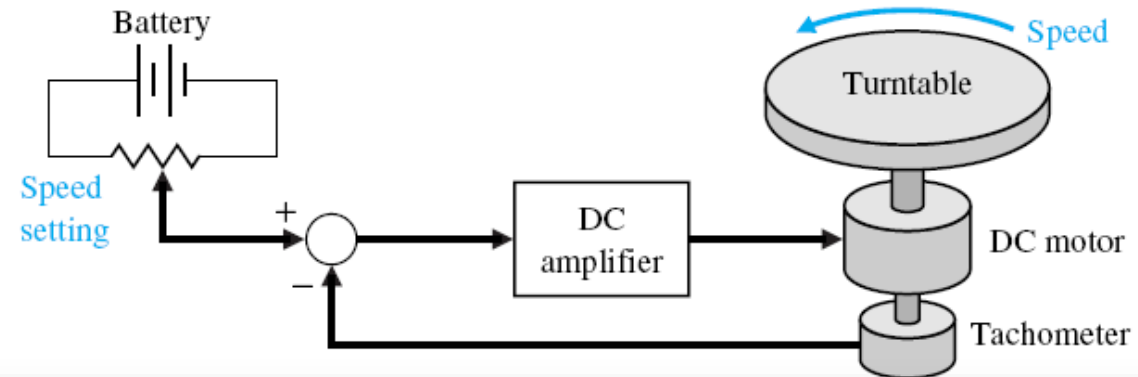
Turntable Speed Control

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

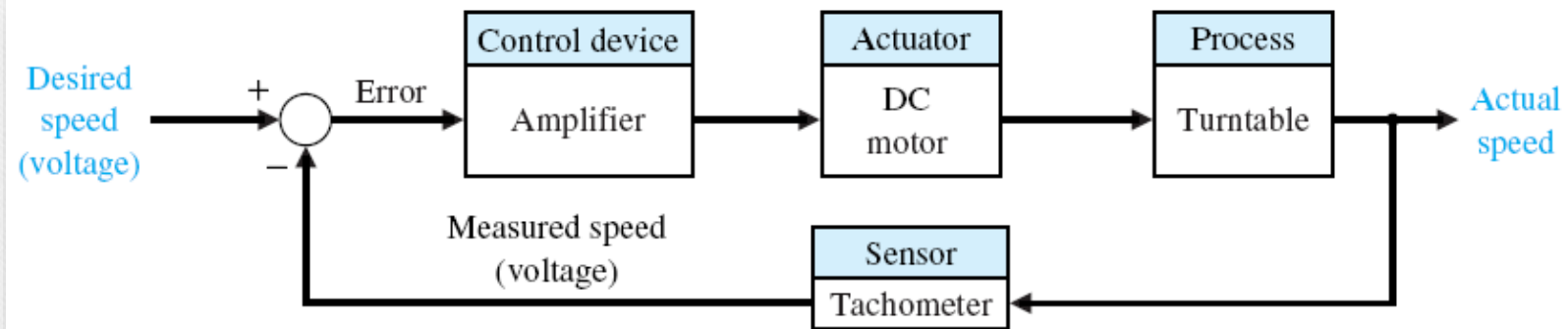


Turntable Speed Control

- Closed-loop control system:

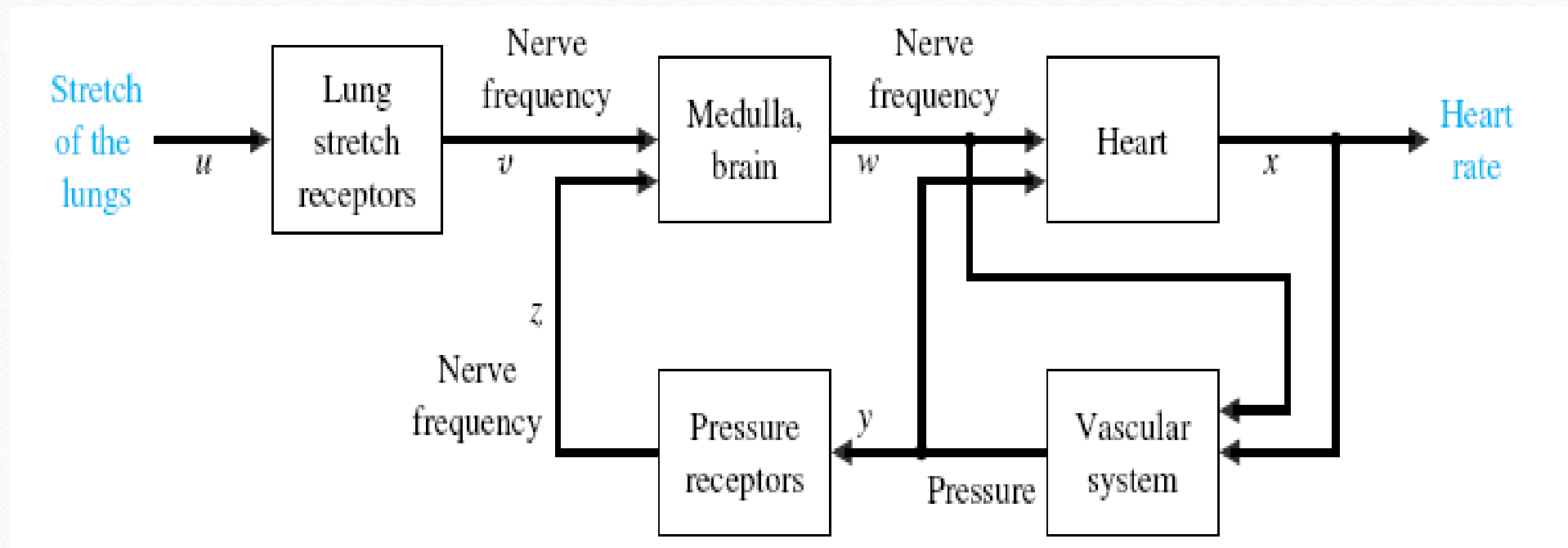


- Block diagram representation:



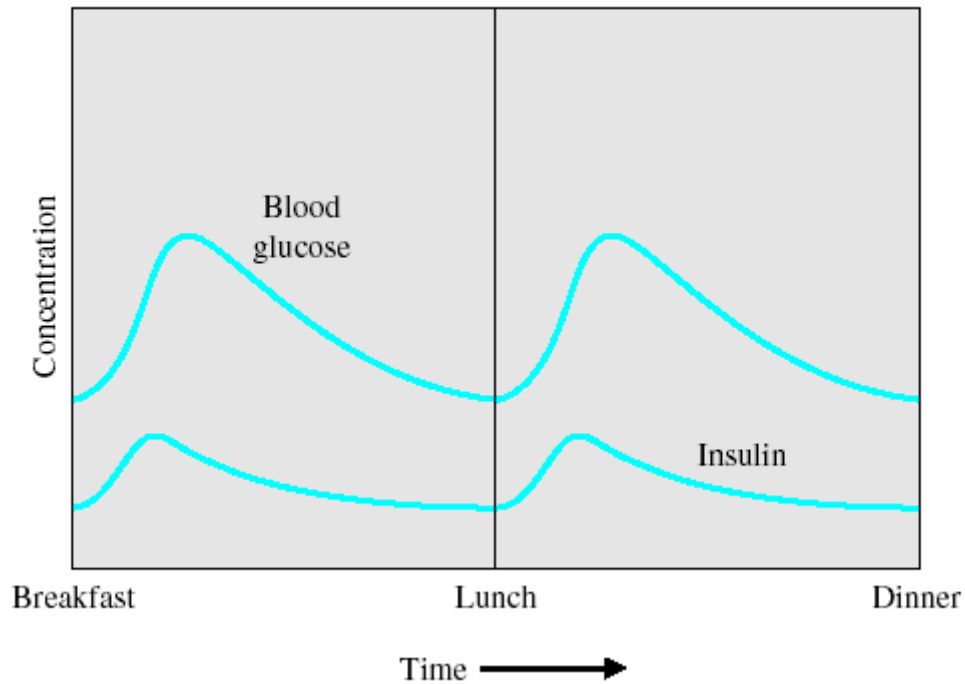
Automatic control system

Design Example



Automatic control system

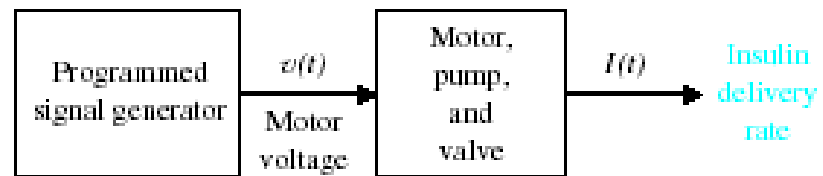
Design Example



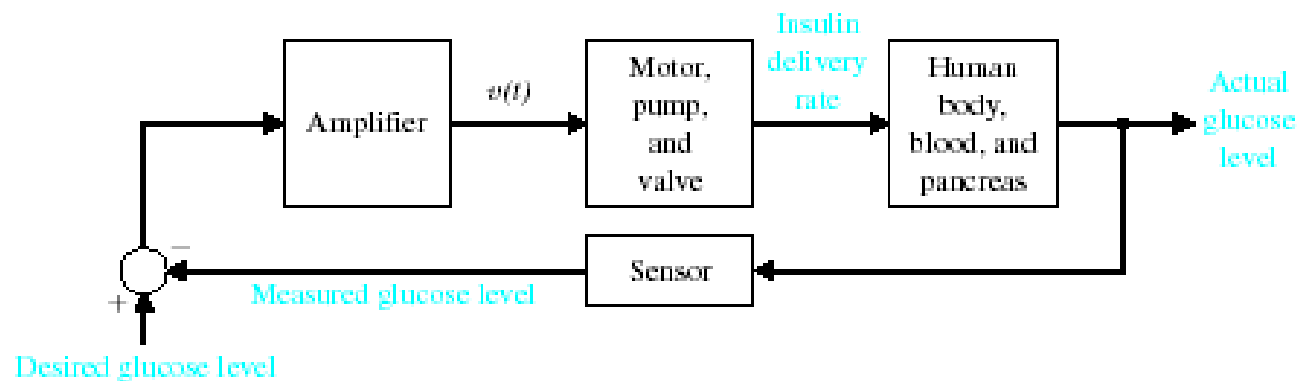
The blood glucose and insulin levels for a healthy person.

Automatic control system

Design Example



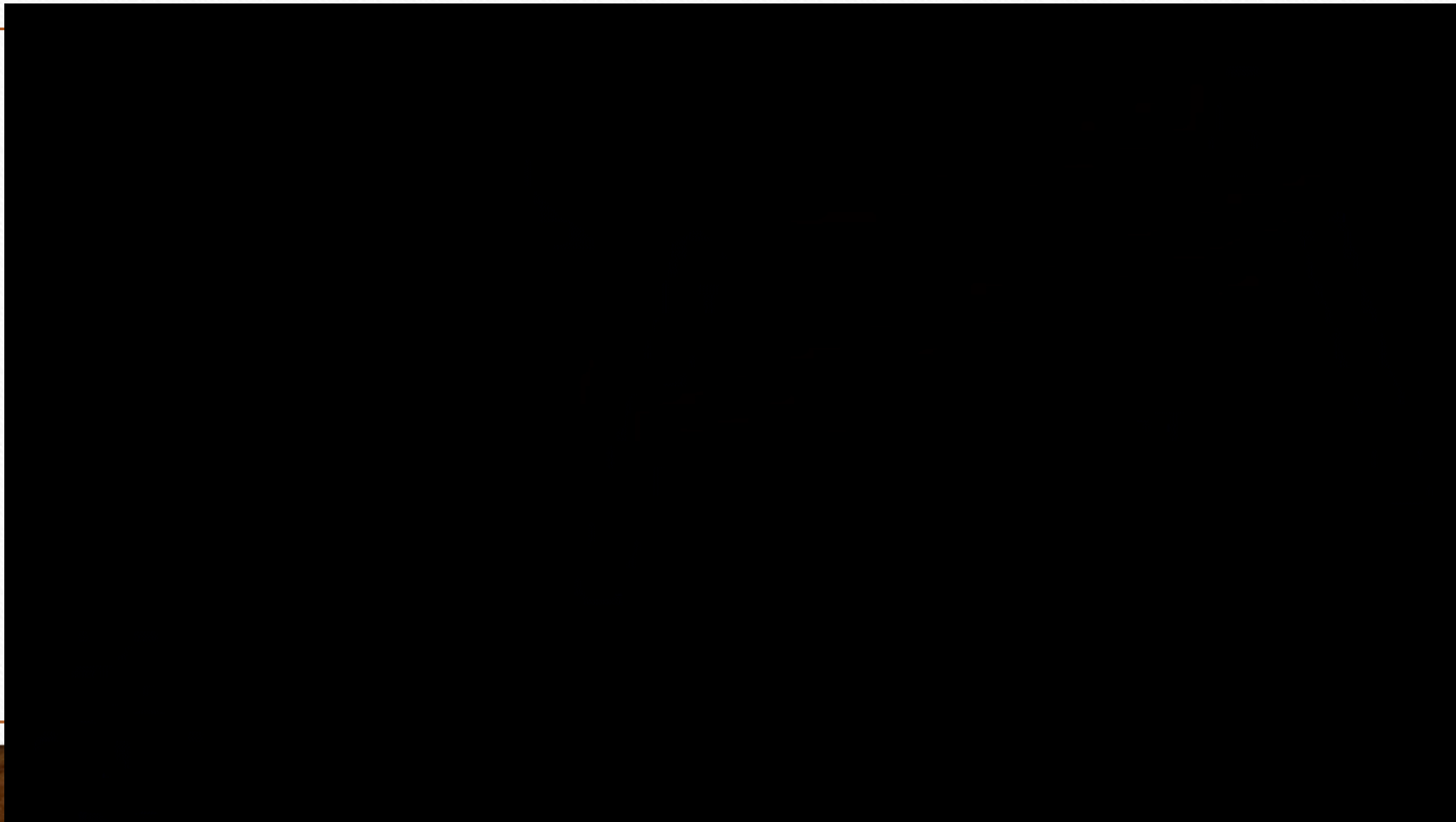
(a)



(b)

(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

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

where s is a complex variable given by

$$s = \sigma + j\omega$$

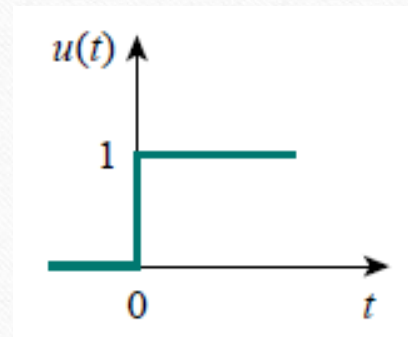
The Laplace transform is an integral transformation of a function $f(t)$ from the time domain into the complex frequency domain, giving $F(s)$.

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Defination of Laplace Transform

a) Step function

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



$$\mathcal{L}[u(t)] = \int_{0^-}^{\infty} 1e^{-st} dt = -\frac{1}{s}e^{-st} \Big|_0^{\infty} = -\frac{1}{s}(0) + \frac{1}{s}(1) = \frac{1}{s}$$

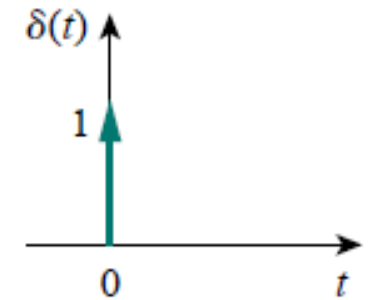
Automatic control system

Defination of Laplace Transform

b) Impulse function

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

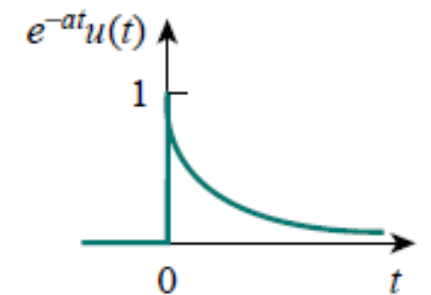
$$= e^{-0} = 1$$



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

$$\begin{aligned} F(s) &= \mathcal{L}[\sin \omega t] = \int_0^{\infty} \underbrace{(\sin \omega t)} e^{-st} dt \\ &= \int_0^{\infty} \left(\frac{e^{j\omega t} - e^{-j\omega t}}{2j} \right) e^{-st} dt \\ &= \frac{1}{2j} \int_0^{\infty} (e^{-(s-j\omega)t} - e^{-(s+j\omega)t}) dt = \frac{1}{2j} \left(\frac{1}{s-j\omega} - \frac{1}{s+j\omega} \right) = \frac{\omega}{s^2 + \omega^2} \end{aligned}$$

Automatic control system

Properties of Laplace Transform

Example

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

Solution

$$\begin{aligned} F(s) &= \mathcal{L}[\sin \omega t] = \int_0^{\infty} \underbrace{(\sin \omega t)} e^{-st} dt \\ &= \int_0^{\infty} \left(\frac{e^{j\omega t} - e^{-j\omega t}}{2j} \right) e^{-st} dt \\ &= \frac{1}{2j} \int_0^{\infty} (e^{-(s-j\omega)t} - e^{-(s+j\omega)t}) dt = \frac{1}{2j} \left(\frac{1}{s-j\omega} - \frac{1}{s+j\omega} \right) = \frac{\omega}{s^2 + \omega^2} \end{aligned}$$

Automatic control system

Properties of Laplace Transform

Time Shift

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

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

$a \geq 0$

$$\left\{ \begin{array}{ll} u(t-a) = 0 & t < a \\ u(t-a) = 1 & t > a \end{array} \right.$$

Automatic control system

Properties 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 $t = x + a$.

$$\begin{aligned}\mathcal{L}[f(t-a)u(t-a)] &= \int_0^{\infty} f(x)e^{-s(x+a)} dx \\ &= e^{-as} \int_0^{\infty} f(x)e^{-sx} dx \\ &= e^{-as} F(s)\end{aligned}$$

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

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Properties of Laplace Transform

Time Differentiation

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

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

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Properties of Laplace Transform

Time Differentiation

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

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

Automatic control system

Properties of Laplace Transform

Time Integration

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

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

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Properties of Laplace Transform

Time Integration

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

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

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

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

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

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

Automatic control system

Properties of Laplace Transform

Initial and Final Values

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

For an example;

$$f(t) = e^{-2t} \cos 10t$$



$$F(s) = \frac{s + 2}{(s + 2)^2 + 10^2}$$

Then;

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

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

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}		$\frac{1}{(s+a)^2}$
$t^2 e^{-at}$		$\frac{2!}{(s+a)^3}$