ME 6102: Design of Mechatronic Systems

Introduction: Motivation contents

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What is learning?

Any guesses?

- Its moving from known to unknown (a child cannot be sitting in class with you right!)
- Its like expanding your common sense you already have

What it is not?

- Not the information, Not memory, not moving from unknown to unknown

So if you feel you are not understanding what would you do?

- Go a step back where you missed and correct or ask questions however trivial you feel they may be

- I read and I forget
- I see and I remember
- I do and I understand

This course is all about doing and understanding: Experiential learning

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What is expected of you?

- BE ETHICAL: the most important. Do not copy/ be truthful/ help others to clear fundes ← You are helping yourself by this
- Be in class physically as well mentally: then you would have to spend less time studying in room
- If you have doubt questions, feel free to ask. It may be common for many
- Be aware of common sense. Ex ball throw, feel for numbers!! ☺
- Give feedback anytime →

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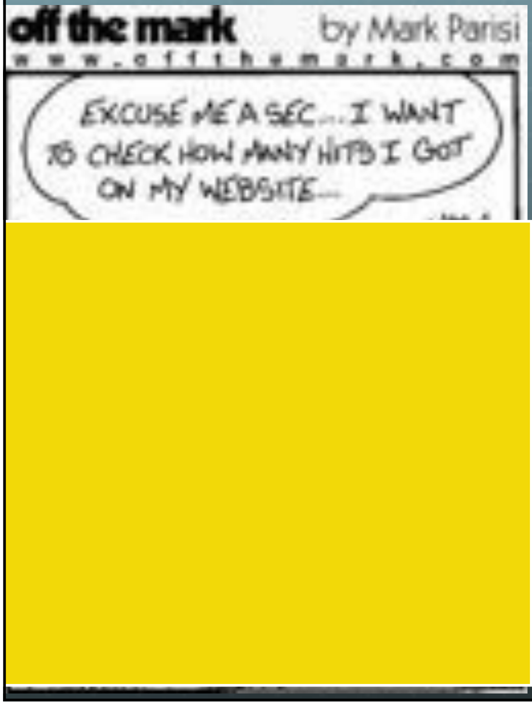


Communication

- Better ask questions and clarify your understanding/ learning

Communication

- Better ask questions and clarify your understanding/ learning

Why study design of mechatronic systems?

- Increasing demands on quality and productivity forces automation. For example Automobile, Aerospace, Energy https://www.youtube.com/watch?v=VpwkT2zV9H0

Q: why it is gaining demand only now??

- Decreased cost of ICs and microprocessors makes low-cost implementation of control easily possible
- Many new features and products previously unthought can be possible Examples
- Future directions:
  - With IoT increasing smartness rests with devices n systems
  - With machine learning AI model based understanding is becoming extinct

Mechatronic Systems

- Application of mechatronic systems
  - Industrial: assembly lines, process plants
    - ABB food processing automation
  - Various new gadgets:

CD ROM drives, automatic xy stages, hard disc drive, robots, cruise control, electronic fuel injection, UAVs, printer, scanner, washing machine, Photocopy (xerox) machine, ATM, missile systems, space rockets, liquid level controller, chemical plant, CNC machine, … the list is endless, Gadgets talking to each other and talking to analytics on clouds for gaining smartness

Understanding Mechatronic systems

- By observing things keenly you will see that the things do make the "common sense" lets not loose our common sense but expand it Ex. Driving a car or riding bicycle!
- Use our existing knowledge/learning to apply and expand domain of understanding
- Basically all learning here comes out of some fundamental laws, keen observation, common sense, geometry and calculus, microprocessor/ signal processing fundamentals,

How these work?

- Floppy drive
- CDROM drive : Gross positioning/ fine positioning servo system
- Scanner
- Hard disc drive
- Micromouse
- Washing machine
- Autofocus camera
- Deskjet printer, laser printer
- 3D printers
- ATM : https://www.youtube.com/watch?v=cYWHqha2wfk

Building mechatronic system

- Ability to see through and define subproblems to be solved and again to solve them break them into simpler cases to gain broad understanding and refine it to make it more complex and perfect as per the needs.
- Ability to manufacture things!! Skills to actually achieve what you desire to achieve
- Example: building motion control platform give some specification.

Course Contents

- Introduction, applications of mechatronic systems. Elements of mechatronic system: Sensor, actuator, plant, and controller. Hands-on experience with CDROM drive, scanner, or similar such system/s.
- Integrated mechanical-electronic design philosophy. Integrated analysis tools and examples, selection of sensors, actuators and drive systems.
- Microcontrollers for mechatronics: interfacing, programming, selection of microcontroller. UI and software requirements.

Course Contents

- Control design in linear and nonlinear domains for rigid body and compliant motion systems, control implementation: various techniques; practical issues in implementation: friction, backlash, noise; digital control fundamentals.
- Signal processing for mechatronics and Fast Fourier Transform (FFT), analog and digital filters, signal processing for nonlinear control.
- Advanced topics in mechatronics: Example:Micro-Mechatronic, Opto-mechatronics.

Course Goals

- Conceive new mechatronic product based on raw idea and develop it further
- Be able to control actuators like motor, voice coil, hydraulic etc. in a closed loop using microprocessor and understand implementation issues
- Interface sensors with microcontrollers using various interfaces
- Develop skill to choose appropriate sensors, actuators, and microcontrollers for a given application

Course Goals

- Be able to develop a reasonable mathematical control amenable model for the system under consideration
- Ability to decide and choose appropriate control strategy and design controller for a given specifications on performance
- See through the signal processing needed for the control implementation

Course Goals

- Modify electronics domain to suit mechanical design simplification and vice versa
- Be able to conceive and further develop solution for industrial process automation based on PLC or alike: If time permits

Foundation Assumed

- Fundamentals of microprocessor and any one programming experience: Arduino, Piccolo stick, XEP 100, DSPic, Raspberry pi, etc.
- Basics of mechanics kinematics and dynamics
- Drawing, solid modeling of mechanical systems
- Basic skills in manufacturing: lathe, drilling, milling, laser cutting.

Course Evaluation

- Quizzes (may have viva): 1 + 1 : 15% Missed quiz: 0
- Assignments: 15%
- Course Project : 25% (4 presentations/ demos for evaluation)
- End sem : 40%
- Class participation: 5%

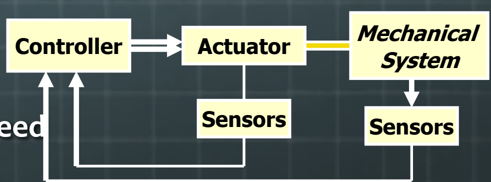
- Moodle
- Optional: Help session 2 hrs if needed Please ask for

Text Books

- Devdas Shetty, Richard A. Kolk, "Mechatronics System Design," PWS Publishing company
- Boukas K, Al-Sunni, Fouad M "Mechatronic,Systems Analysis, Design and Implementation," Springer,
- Sabri Cetinkunt, "Mechatronics with Experiments," 2nd Edition, Wiley
- Janschek, Klaus, "Mechatronic Systems Design," Springer,

Elements of Mechatronic System

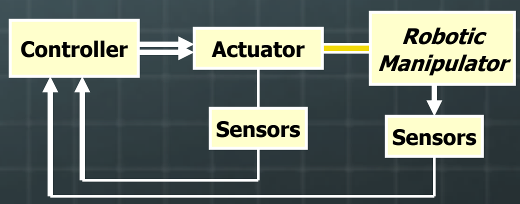
- Concept: Example "Driving of a car"
  - Actuators: Engine of the car, your hands, legs
  - Sensors: Your eyes, ears, etc.
  - Controller: "your brain"
  - Plant: Car
  - Feedback: position and speed



Typical elements of a Mechatronic system

Example: Robot Manipulator

- In case of a typical robot:
  - Actuators: motors + transmission, hydraulic cylinders
  - Sensors: encoders, tachometers, potentiometers, force sensors (strain gauge), accelerometers, gyroscopes, cameras (vision)
  - Controller: analog or digital (computer)
  - Plant: Robot
  - Feedback: position and speed of joint or end-effecter, force, acceleration etc.



Typical elements of a robotic system

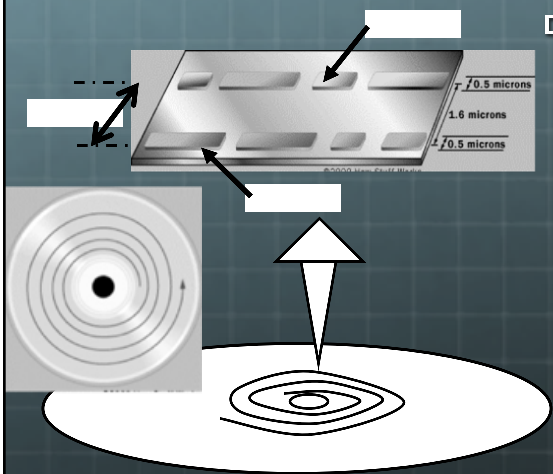
Kawasaki Manipulator

- Z series 6 axis robot
- Spot welding, stud welding, palletizing, dispensing, racking, material handling, machine tending, press tending, part transfer, assembly
- The patented Kawasaki Hybrid Link Configuration allows turning backward with low power consumption.

Auto-focus Cameras

- Autofocus Camera
  - Autofocus
  - Focus lock
  - Built-in flash with red-eye reduction
  - Auto power shut-off
- Older versions
  - Auto (DX) film speed setting
  - Auto film load and advance
  - Motorized film rewind

CD ROM Drive

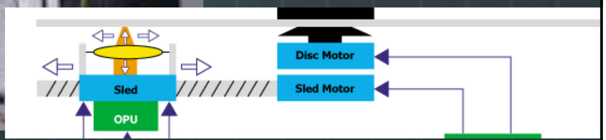


Data storage and reading

- Laser reading head
- Data in form of land and pits
- Various sub-systems
  - Positioning of head
  - Optical system
  - Spindle rotation

CD ROM Drive

Various systems



Various systems

- Positioning of head
- Spindle rotation
- Optical system

Quad Copter

Parrot AR:Drone

Range 50m controlled by Ipod.

Various systems

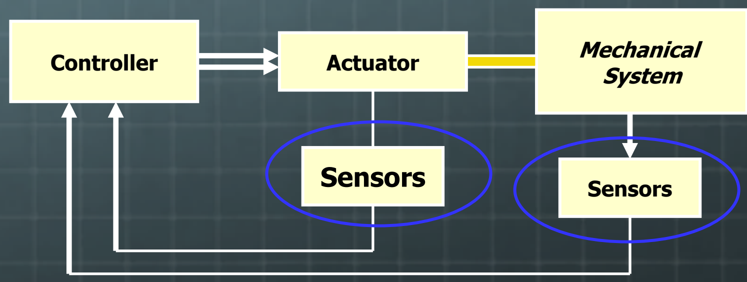
- Stabilization in air
- Various motions

Sensors

- Accelerometers
- Gyros
- Cameras 2

Elements of mechatronic system

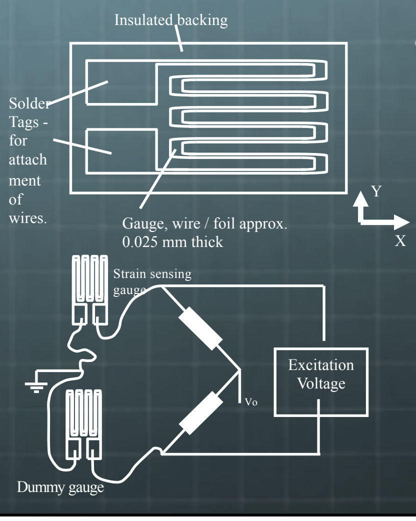
- fundamental structure: next Sensors



Sensors Classification

- Based on output signal
  - Analog
  - Digital
- Based on the principle of operation:
  - Resistive, capasitive, inductive
  - Resonating:
  - Optical: Fiber optic, encoders etc.
  - Magnetic: Hall effect
  - Piezoelectric transducers
  - Ultrasonic sensors

Resistive Sensors



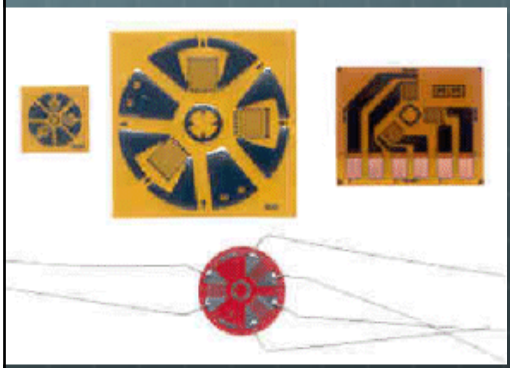
- Potentiometers
- Strain gauges:
  - Principle
  - Wheatston bridge measurement

$$\varepsilon_a = \frac{4V_o}{V} \times \frac{1}{GF}$$

GF = 2 to 4

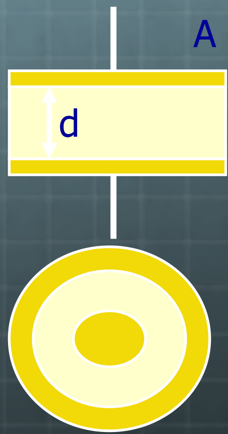
  - Temperature compensation
  - Noise issues
  - Single axis measurement

Resistive Sensors



- Strain rosettes: multiaxis
- Applications
  - Force measurement
  - Torque measurement

Capacitive Sensors

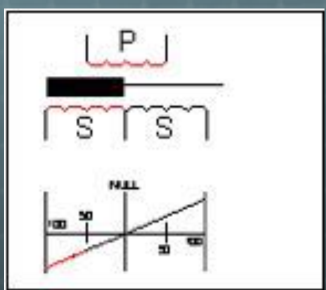


- Basic Principle

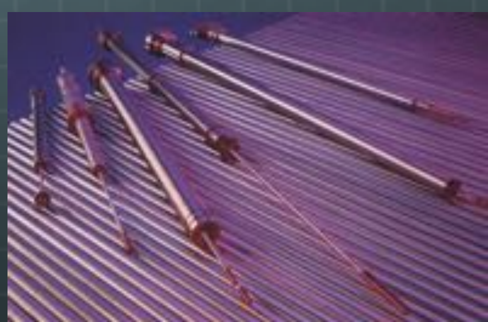
$$C = \varepsilon_0 \varepsilon_r A / d$$

- Configurations
  - Flat plates
  - Cylindrical
- Applications
  - Displacement measurement

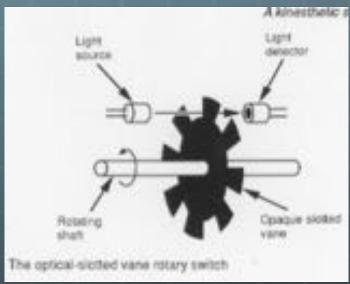
Inductive Sensors



- LVDT: Linear variable displacement transducer
- Principle: figure



Optical Sensors



Basic principle

- Components
  - Light source
  - Photodetectors
- Processing electronics

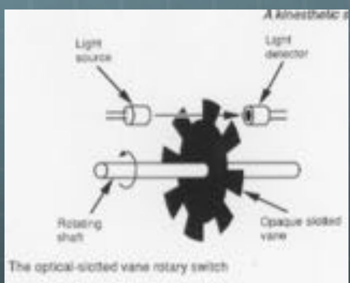
Variations

- Using Moire fringes
- Using diffraction effect
- Fibre optics sensors

Advantages

-High accuracy possible
-Less noise, digital
-Long life, reliable

Optical Sensors: Encoders



- Basic principle
- Components
  - Light source
  - Photodetectors
  - Processing electronics
- Variations
  - Absolute encoders
  - Incremental encoders

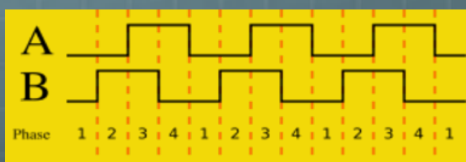
Advantages

-High accuracy possible
-Less noise, digital
-Long life, reliable

Optical Sensors: Incremental encoder

- Just slits to generate pulses
- How to sense direction?? Two sensors
- Two outputs if at 90° out of phase with each other – quadrature output
- Third sensor required for determination of absolute position

Optical Sensors: Incremental encoder



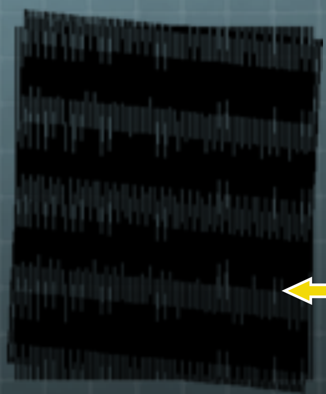
Phase	A	B
1	0	0
2	0	1
3	1	1
4	1	0

Gray Coding for Clockwise Rotation

Phase	A	B
1	0	0
2	1	0
3	1	1
4	0	1

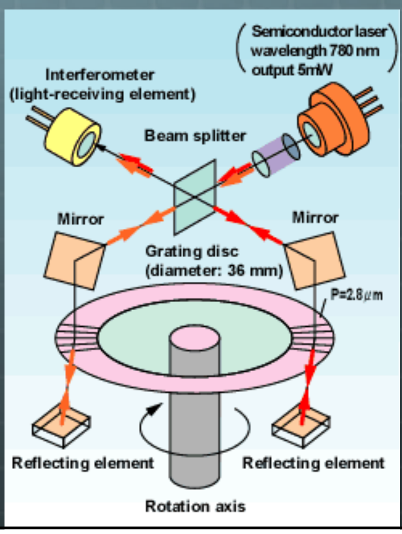
Gray Coding for Anti Clockwise Rotation

Optical Sensors



- Basic principle
- Components
  - Light source
  - Photodetectors
  - Processing electronics
- Variations
  - Using Moire fringes
  - Using diffraction effect
  - Fibre optics sensors

Optical Sensors



Cannon encoder

- 81,000 grating patterns
- 36-mm grating disc
- Diffraction of light
- Interference to produce detection signal

Optical Sensors in Auto-focus Cameras

Sensors

- Range finder: infrared
- Optical imager: ccd (charge coupled device)
- Film position and advance sensor

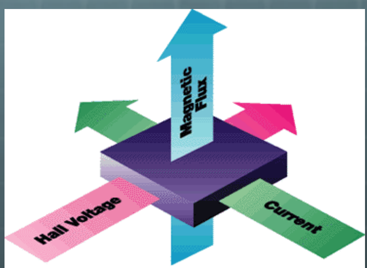
Optical Sensors in Auto-focus Cameras

- Sensors (SLR camera)
  - Optical imager: ccd (charge coupled device)

Optical Sensors: Encoders

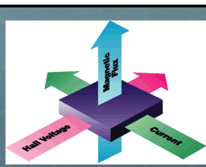
- Linear encoders
  - sensor, transducer paired with a scale that encodes position.
  - sensor reads the scale in order to convert the encoded position into an analog or digital signal
- Rotary encoders
  - Absolute
  - Incremental

Magnetic Sensors

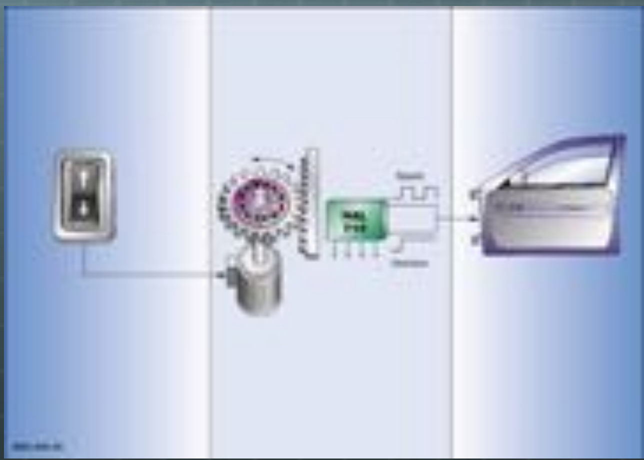


- Inductive:
- Hall effect
  - Principle
  - Semiconductor can be used
  - High sensitivity
  - Small sizes
- Application examples
  - CDROM spindle motor
  - Power window unit in cars

Hall effect sensors



Power window unit in cars



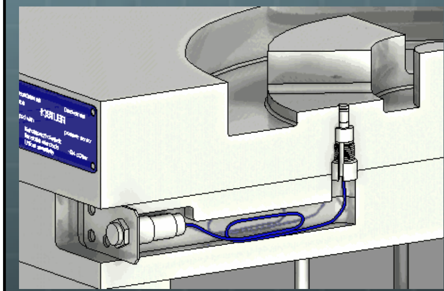
Piezoelectric Sensors

- **Principle: generation of charge on application of force**
  Charge generator and capasitor
  ***Q = dF d* is piezoelectric coefficient. Hooks law**
  using capacitor relation

$$Q = \frac{dAE\Delta t}{t} \qquad V = \frac{dtF}{\varepsilon_r \varepsilon_0 A}$$

- **Materials**
  - **Quartz crystal (SiO_2)**
  - **PZT (lead zirconium titanate)**
  - **PVFD (polyvinylidene fluoride)**

Piezoelectric Sensors



- Advantages:
  - High frequencies
  - Both actuation and sensing possible
- Applications
  - Micro electro-mechanical systems (MEMS)
  - Force, pressure, acceleration measurements
  - Vibration measurements

MEMS Based Sensors

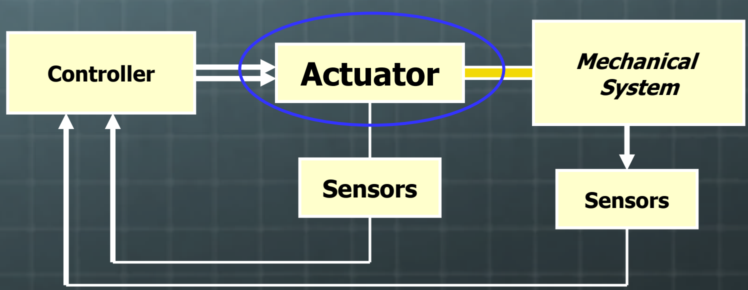
MEMS (MicroElectroMechanical Systems)

- MEMS refer to miniature mechatronic systems bulk fabricated using VLSI technology
- Advantage:
  - both mechanical and electronic components on the same chip
  - Low cost mass fabrication
- Techniques and processes to design and create miniature systems
- Miniature embedded systems

Sensor Selection for Mechatronic System

- System requirements → Sensor requirements
  - Example: servomotor for robotic application
  - Kinematic/dynamic analysis to get the required sensor specs
- Noise considerations
  - Choice of analog vs digital sensor
  - Use of filters: analog vs digital domain implementation
- Cost implications
- Mathematical model of the system/sensor, preliminary simulation
- Manufacturers catalogs → proper choice

- Next element of mechatronic system



Actuators

Types of actuators in mechatronic system

- Solenoids
- AC and DC motors
- Stepper motors
- Hydraulic actuators
- Piezoelectric motors
- Pneumatic devices

DC Motors

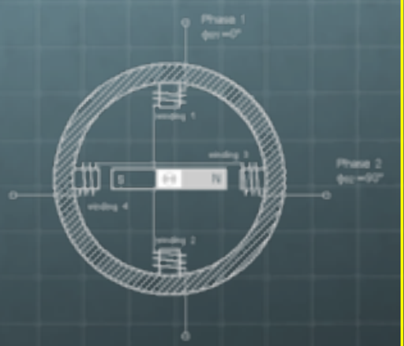
- Principle: wire carrying conductor in magnetic field
- Two primary classes
  - Brush type DC motors
  - Brushless DC motors - speeds 100,000 rpm
    - solid state switching
- Wide variety of motors available in market
  - Speeds and torque ranges
  - Sizes, voltage ranges
  - Bandwidth ranges

Stepper motors

- High torque at low speeds
- Stepping action in motion
- Ideal for implementation of digital control
- Holding toque → eliminates need for brakes
- Several constructions and configurations possible
- Types
  - Permanent magnet stepper motors
  - Variable reluctance stepper motors

Stepper motors

- Operation: principle



Clockwise Rotation

Index	1a	1b	2a	2b
1	1	0	0	1
2	1	1	0	0
3	0	1	1	0
4	0	0	1	1
5	1	0	0	1
6	1	1	0	0
7	0	1	1	0
8	0	0	1	1

Alternate Full Step Sequence
(Provides more torque)

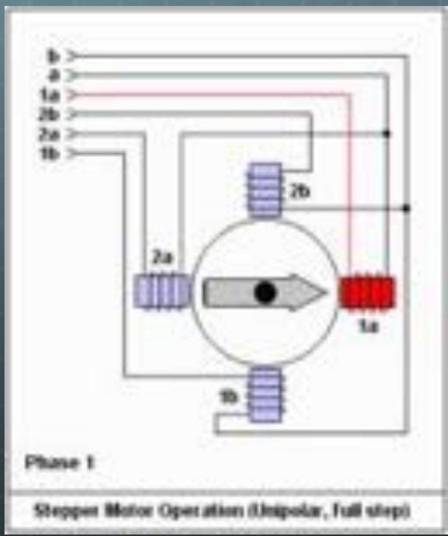
Clockwise Rotation

Index	1a	1b	2a	2b
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1
9	1	0	0	0
10	1	1	0	0
11	0	1	0	0
12	0	1	1	0
13	0	0	1	0
14	0	0	1	1
15	0	0	0	1
16	1	0	0	1

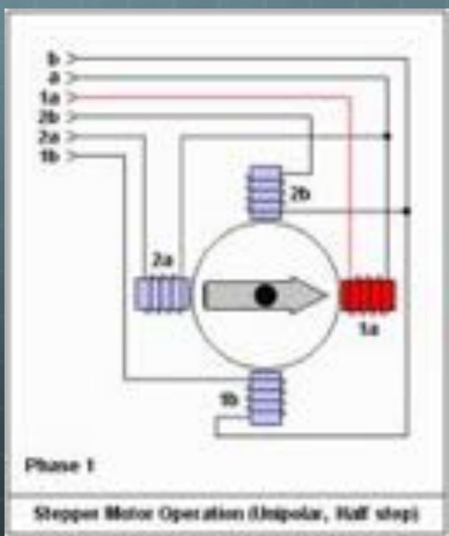
Half Step Sequence

- Various logics possible

Stepper motors



Stepper motors



- Applications
  - Dot matrix printers
  - Floppy drives
  - Robots
  - Scanner
  - X ray machines
  - Old CDROM drives

Hydraulic Actuators

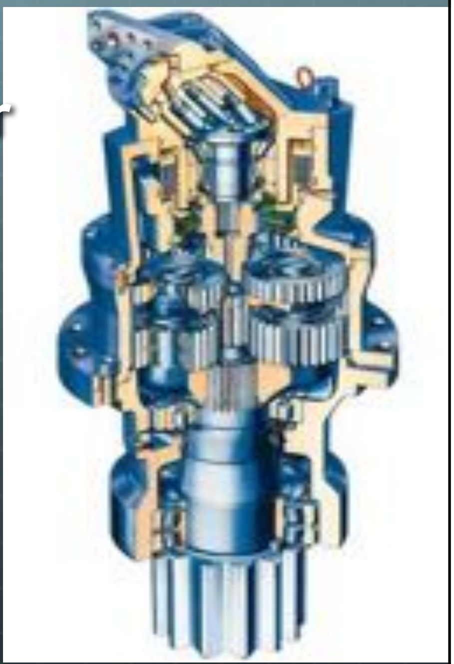
- Piston type linear actuators and hydraulic motor
- High forces/torques in a small place
- Low inertia and very fast response
- Types of hydraulic motors:
  - Gear/vane motor
  - Axial piston motor or swash plate motor
- Applications:

  Conveyer belts, earth moving machinery, material handling equipments, heavy machinery

Industrial Hydraulic Motor

MOBILEX GFB axial piston hydraulic drive unit along with gear reduction.

From BOSCH REXROTH



Hydraulic Actuator Applications

Feeders and conveyor belts: fluctuations in load

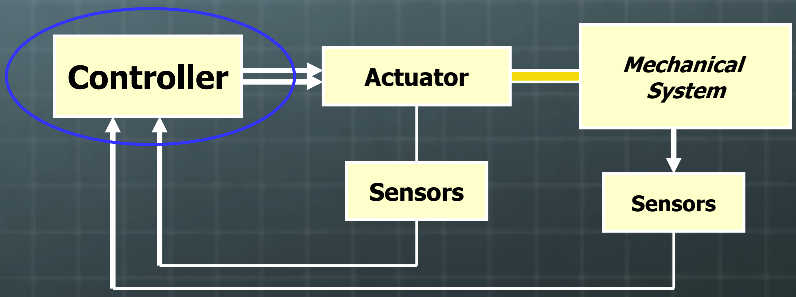
Hagglunds Drives AB

Hydraulic Actuator Applications

This 364t capacity coal dumper is equipped with a

HYDROTRAC GFT drive unit

- Final element of mechatronic system



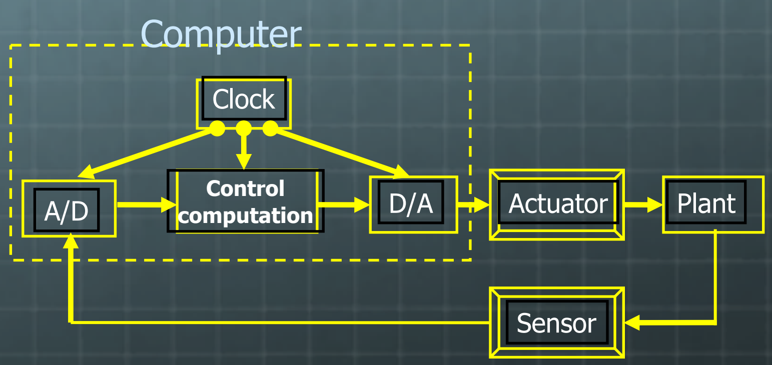
Controllers

- An important element of mechatronic system
- Wise design of controller → substantial cost savings and performance improvement
  - Example: controller used for hard disk drive
- Types: based on algorithm:
  - PD, PID, robust, adaptive, nonlinear, fuzzy logic, optimal.
- Types: based on implementation
  - Analog domain controllers: electronic circuit
  - Digital domain controllers: microprocessor/ computer

Important Issues in Design and Analysis

- Stability: various notions
  - Asymptotic stability
  - Exponential stability
- Controllability (linear systems)
  - Controllable if system can be taken from one to another state in finite time
  - Conditions on A,B,C,D for controllability
- Observability (linear systems)
  - State estimation possible from measurement of *y(t)*
- Standard tools available in MATLAB for analysis

Digital Control Implementation



Controller Implementation

- Issues in digital control implementation
  - Sampling time: example movie, fan
  - Effect on system due to sampling
  - Filters necessary for different computations ex. Derivative computation of PD control
  - Speed of computation
  - Speed of A/D and D/A conversion
  - Number of sensors and actuators
  - Noise coming from various sources
  - Cost