Lecture # 9
Sensors and Actuators

Sensors and Actuators

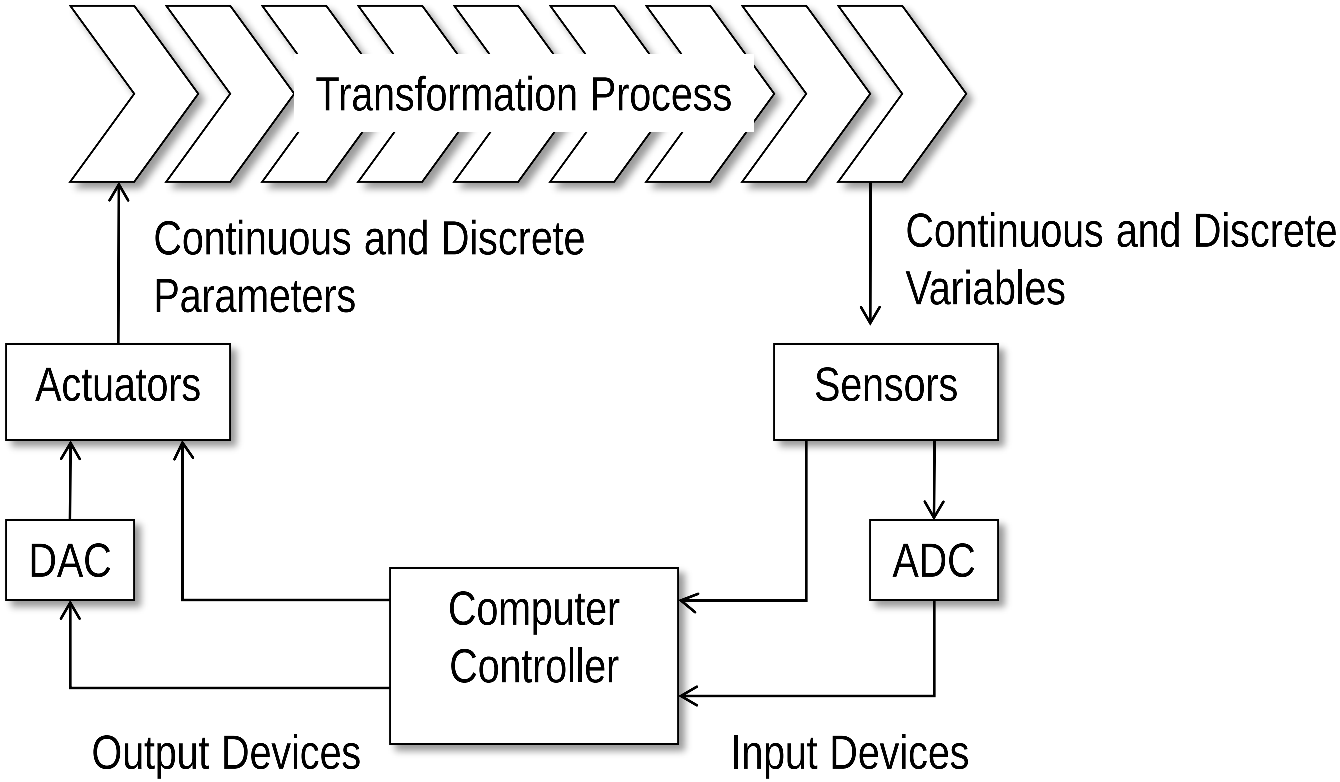
Sections:

1. Sensors
2. Actuators
3. Analog-to-Digital Conversion
4. Digital-to-Analog Conversion
5. Input/Output Devices for Discrete Data

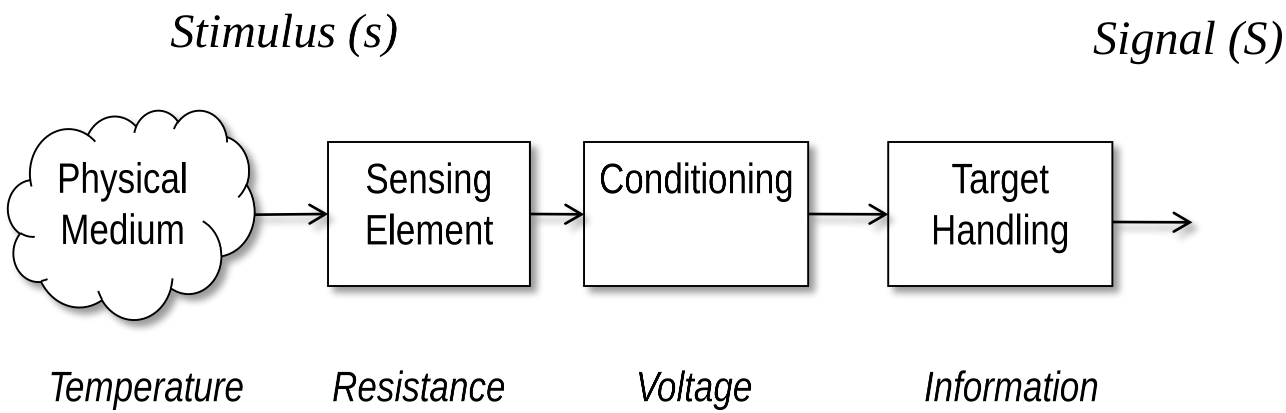
Computer-Process Interface

- To implement process control, the computer must collect data from and transmit signals to the production process
- Components required to implement the interface:
  - Sensors to measure continuous and discrete process variables
  - Actuators to drive continuous and discrete process parameters
  - Devices for ADC and DAC
  - I/O devices for discrete data

Computer Process Control System



Sensors



Transducers

Micro-sensors 10^{-6}m

Transfer Function

$$S = f(s)$$

where S = output signal; s = stimulus; and *f(s)* = functional relationship

For binary sensors: $S = 1$ if $s > 0$ and $S = 0$ if $s \le 0$.

The ideal functional form for an analogue measuring device is a simple proportional relationship, such as:

$$S = C + ms$$

where C = output value at a stimulus value of zero

and m = constant of proportionality (sensitivity)

Example

- The output voltage of a particular thermocouple sensor is registered to be 42.3 mV at temperature 105°C. It had previously been set to emit a zero voltage at 0°C. Since an output/input relationship exists between the two temperatures, determine (1) the transfer function of the thermocouple, and (2) the temperature corresponding to a voltage output of 15.8 mV.

Solution

$$S = C + ms$$

42.3 mV = 0 + m(105°C) = m(105°C)

or m = 0.4028571429

S = 0.4 (s)

15.8 mV = 0.4 (s)

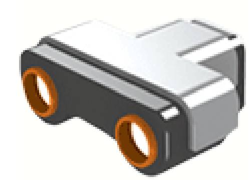
15.8 / 0.4 = s

s = 39.22°C

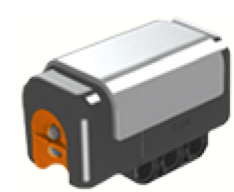
Sensors

A sensor is a transducer that converts a physical stimulus from one form into a more useful form to measure the stimulus

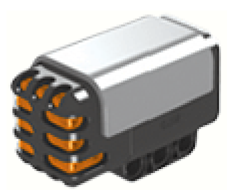
- Two basic categories:
  1. Analog
  2. Discrete
     - Binary
     - Digital (e.g., pulse counter)



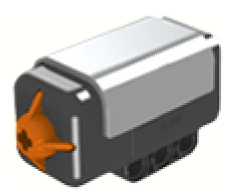
Ultrasonic (distance)



Light (light intensity)



Sound (db pressure)

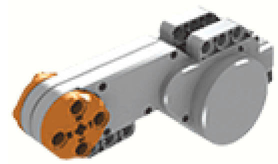


Touch

Other Sensors

- Temperature
- RFID
- Barcode
- Proximity
- Vision
- Gyroscope
- Compass
- Tilt/Acceleration
- Etc.

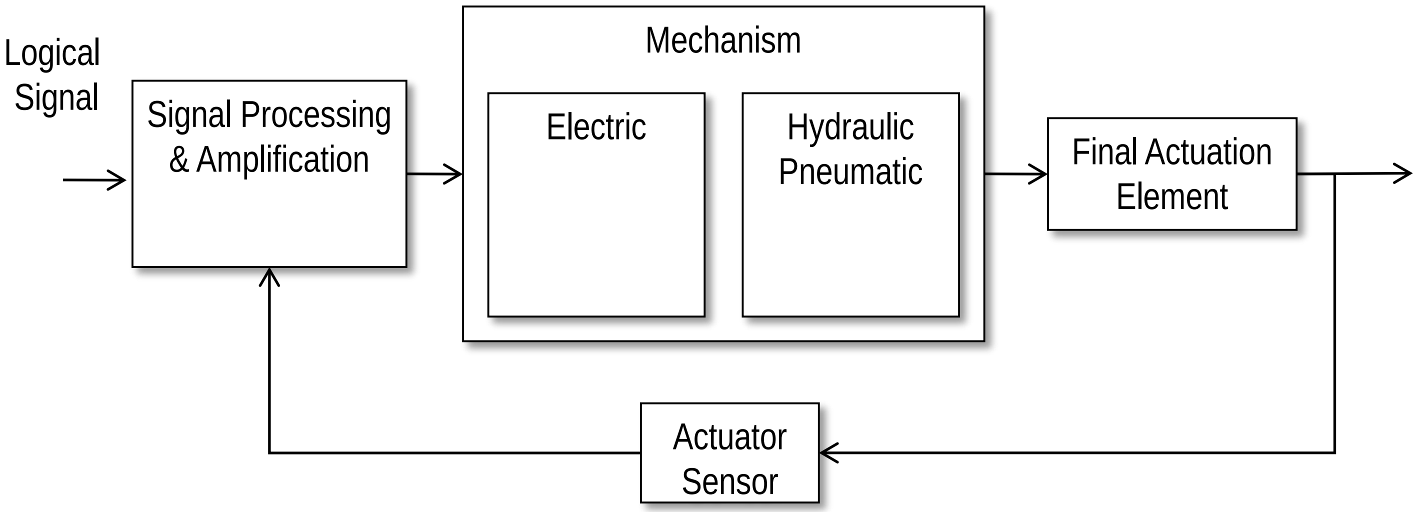
Actuators



Hardware devices that convert a controller command signal into a change in a physical parameter

- The change is usually mechanical (e.g., position or velocity)
- An actuator is also a transducer because it changes one type of physical quantity into some alternative form
- An actuator is usually activated by a low-level command signal, so an amplifier may be required to provide sufficient power to drive the actuator

Actuators

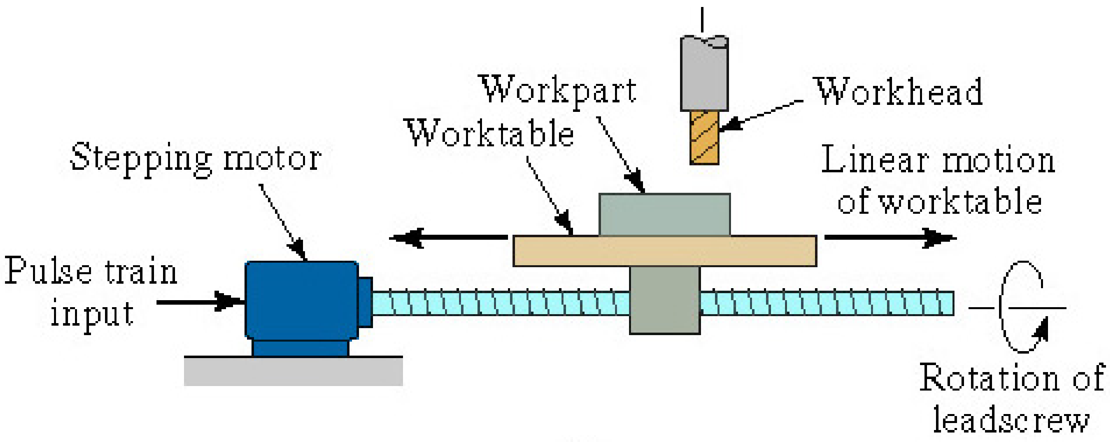


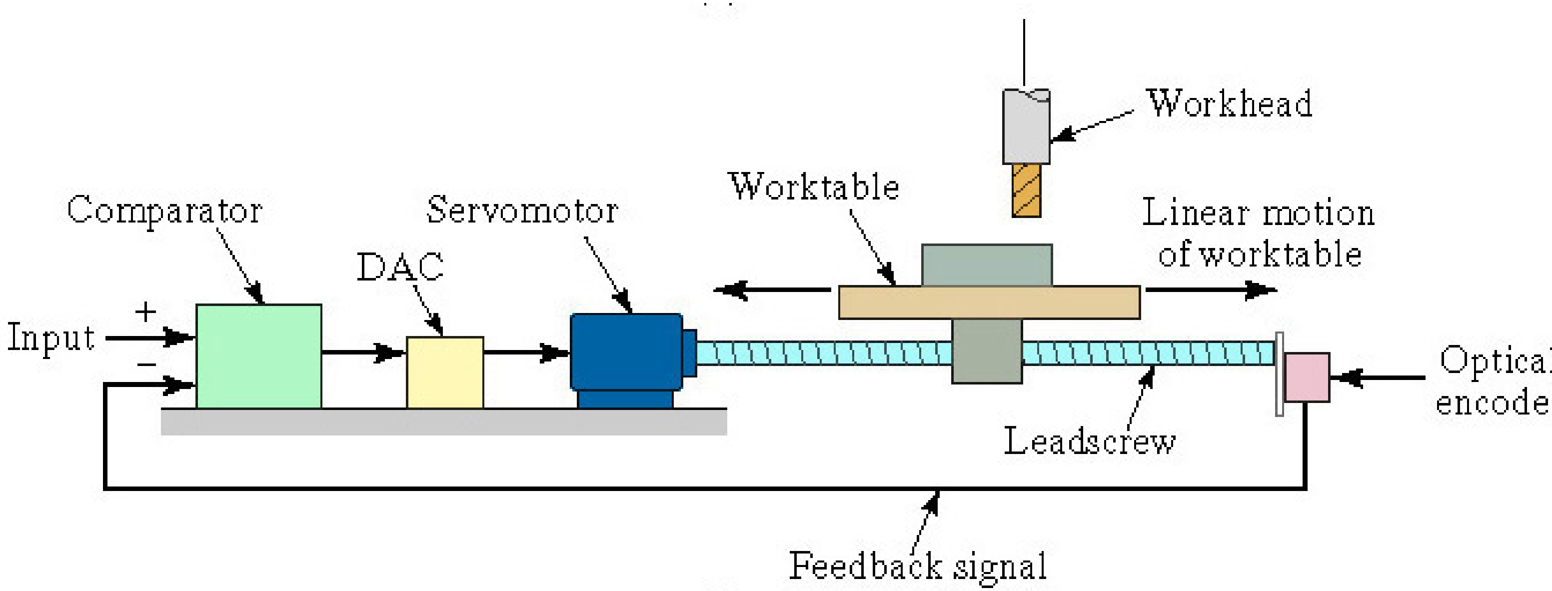
Logical
Signal
Signal Processing
& Amplification
Mechanism
Electric
Hydraulic
Pneumatic
Final Actuation
Element
Actuator
Sensor

Types of Actuators

1. Electrical actuators
   - Electric motors
     - DC servomotors
     - AC motors
     - Stepper motors
   - Solenoids
2. Hydraulic actuators
   - Use hydraulic fluid to amplify the controlle command signal
3. Pneumatic actuators
   - Use compressed air as the driving force

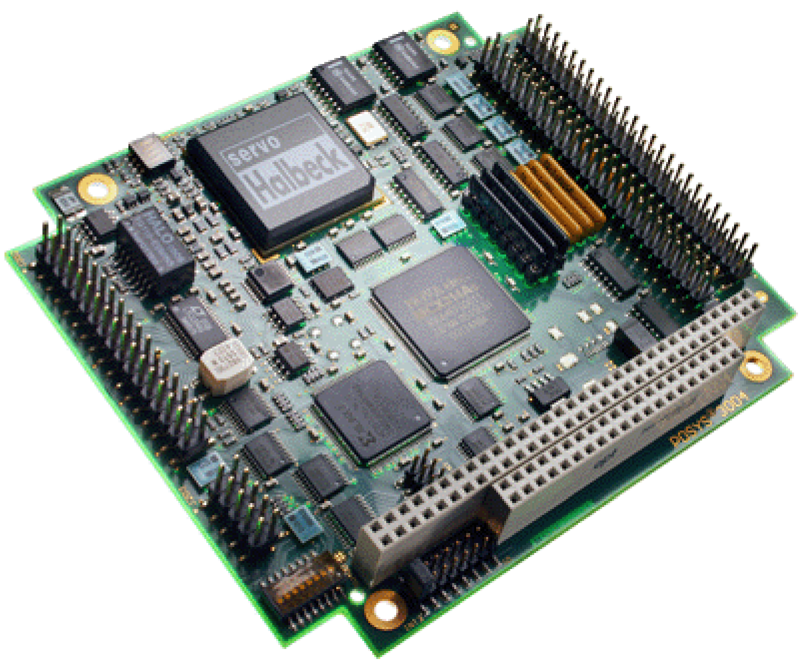
Stepper motor and Servomotor



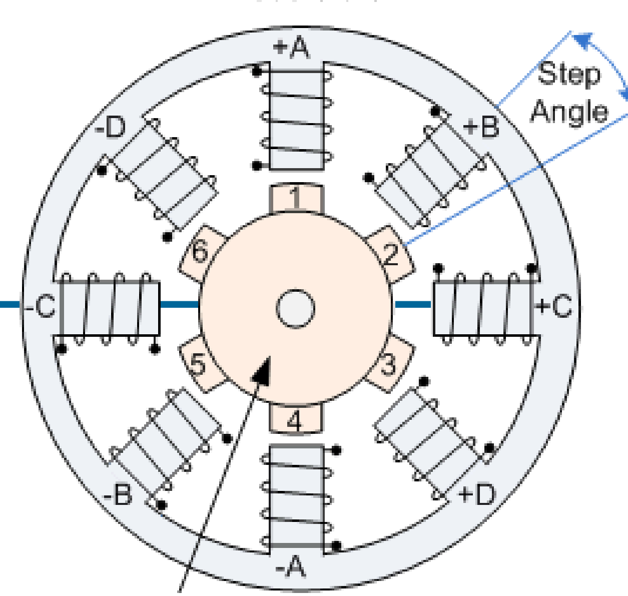


Motor Controllers

Motor Controllers is designed to control up many axes of servo and stepper motors and provides hardware linear, circular, Bit Pattern and continuous interpolation which allow to perform the most complex motion profiles.



Stepper Motors



Step angle is given by: : $$\alpha = \frac{360}{n_s}$$

where n_s is the number of steps for the stepper motor (integer)

Total angle through which the motor rotates (A_m) is given by: $$A_m = n_p \alpha$$

where n_p = number of pulses received by the motor.

Angular velocity is given by: $$\omega = \frac{2\pi f_p}{n_s}$$ where f_p = pulse frequency

Speed of rotation is given by: $$N = \frac{60 f_p}{n_s}$$

Example

- A stepper motor has a step angle = 3.6°. (1) How many pulses are required for the motor to rotate through ten complete revolutions? (2) What pulse frequency is required for the motor to rotate at a speed of 100 rev/min?

Solution

$$\alpha = \frac{360}{n_s}$$

(1) 3.6° = 360 / n_s;   3.6° (n_s) = 360; n_s = 360 / 3.6 = 100 step angles

$$A_m = n_p \alpha$$

(2) Ten complete revolutions: 10(360°) = 3600° = A_m

Therefore n_p = 3600 / 3.6 = 1000 pulses

$$N = \frac{60 f_p}{n_s}$$

Where N = 100 rev/min:

100 = 60 f_p / 100

10,000 = 60 f_p

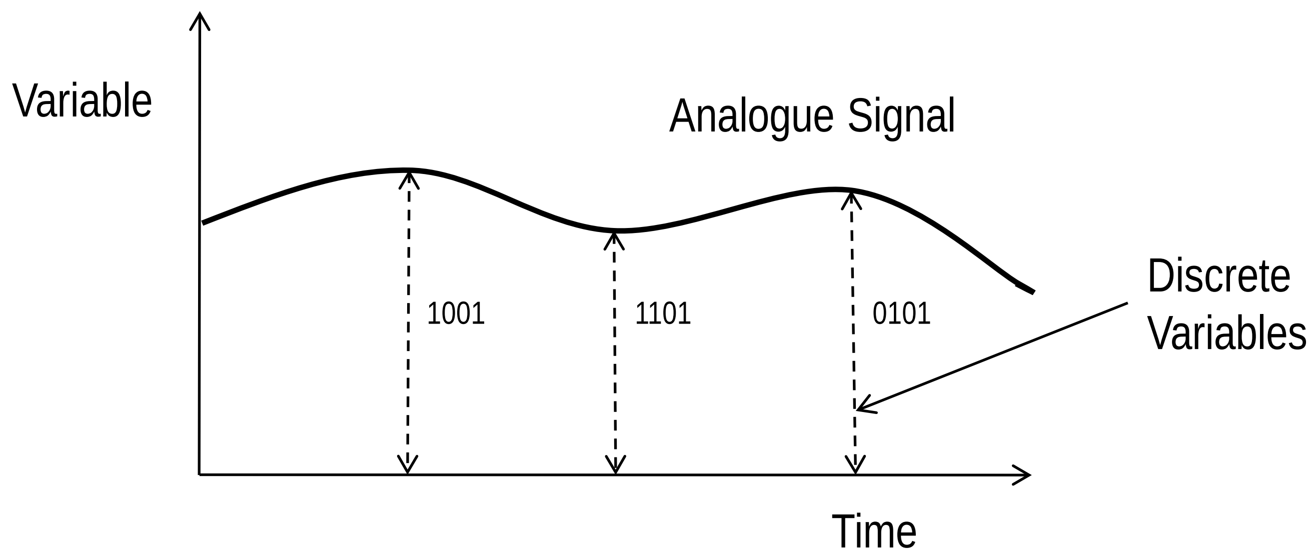
f_p = 10,000 / 60 = 166.667 = 167 Hz

Analog-to-Digital Conversion

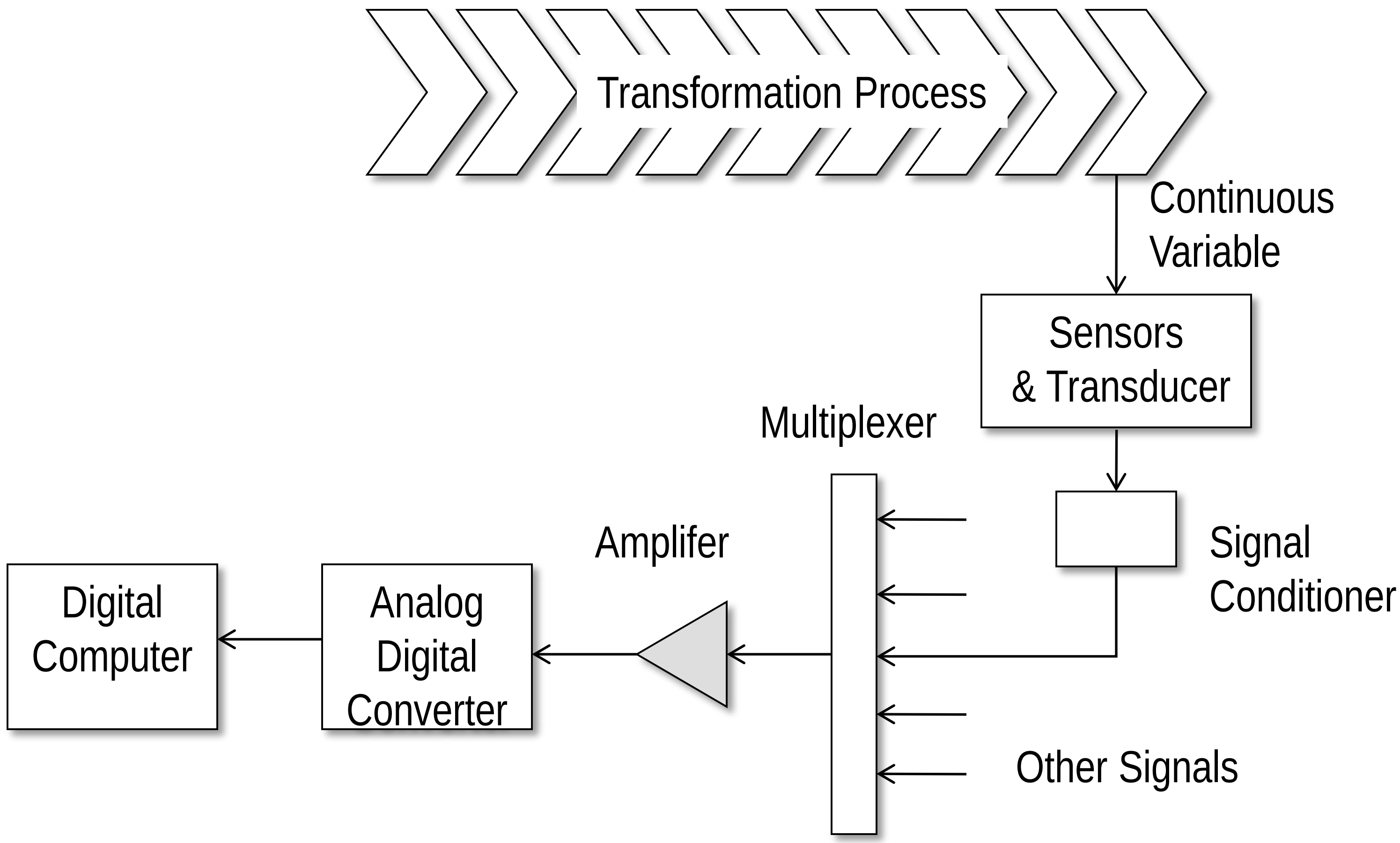
Sampling – converts the continuous signal into a series of discrete analog signals at periodic intervals

Quantization – each discrete analog is converted into one of a finite number of (previously defined) discrete amplitude levels

Encoding – discrete amplitude levels are converted into digital code



Hardware Devices in Analog-to-Digital Conversion



Features of an ADC

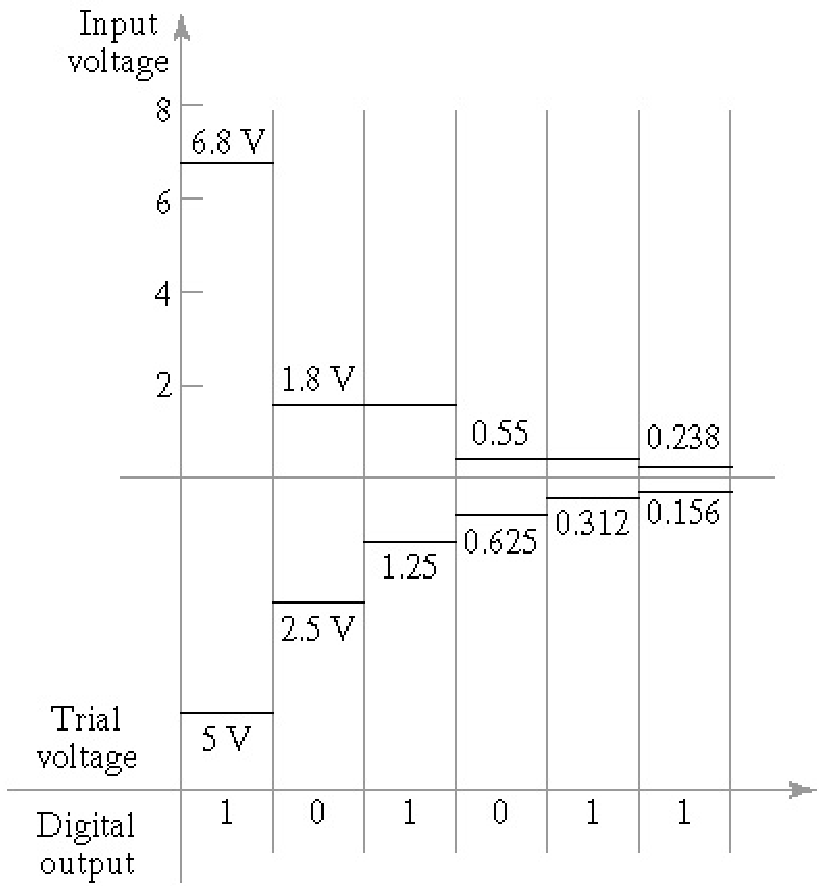
- Sampling rate – rate at which continuous analog signal is polled e.g. 1000 samples/sec
- Quantization – divide analog signal into discrete levels
- Resolution – depends on number of quantization levels
- Conversion time – how long it takes to convert the sampled signal to digital code
- Conversion method – means by which analog signal is encoded into digital equivalent

Successive Approximation Method

- A series of trial voltages are successively compared to the input signal whose value is unknown
- Number of trial voltages = number of bits used to encode the signal
- First trial voltage is 1/2 the full scale range of the ADC
- If the remainder of the input voltage exceeds the trial voltage, then a bit value of 1 is entered, if less than trial voltage then a bit value of zero is entered
- The successive bit values, multiplied by their respective trial voltages and added, becomes the encoded value of the input signal

Example

- Analogue signal is 6.8 volts. Encode, using SAM, the signal for a 6 bit register with a full scale range of 10 volts.



For six digit precision, the resulting binary digital value is 101011, which is interrupted as:

1×5.0 V
0×2.5 V
1×1.25 V
0×0.625 V
1×0.312 V
1×0.156 V

Total = 6.718 V

Resolution

Quantisation levels is defined as: $$N_q = 2^n$$

where N_q = quantisation levels; and n is the number of bits.

Resolution is defined as: $$R_{ADC} = \frac{L}{N_q - 1} = \frac{L}{2^n - 1}$$

where R_{ADC} is the resolution of the ADC; L is the full-scale range of the ADC

Quantisation generates an error, because the digitised signal is only sampled from the original analogue signal. The maximum possible error occurs when the true value of the analogue signal is on the borderline between two adjacent quantisation levels, in which case the error is half the quantisation-level spacing; this gives us the following for quantisation error (*Quanerr*):

$$Quanerr = \pm \frac{1}{2} R_{ADC}$$

where R_{ADC} is the resolution of the ADC.

Example

- Using an analogue-to-digital converter, a continuous voltage signal is to be converted into its digital counterpart. The maximum voltage range is ±25 V. The ADC has a 16-bit capacity, and full scale range of 60 V. Determine (1) number of quantization levels, (2) resolution, (3) the spacing of each quantisation level, and the quantisation error for this ADC.

Solution

$$N_q = 2^n$$

$$R_{ADC} = \frac{L}{N_q - 1} = \frac{L}{2^n - 1}$$

$$Quanerr = \pm \frac{1}{2} R_{ADC}$$

(1) Number of quantization levels:

= 2^{16} = 65,536

(2) Resolution:

R_{ADC} = 60 / 65,536 -1 = ± 0.0009155 volts

(3) Quantisation error:

= ± (0.0009155)/2 = ± 0.00045778 volts

Digital-to-Analog Conversion

- Convert digital values into continuous analogue signal
  - Decoding digital value to an analogue value at discrete moments in time based on value within register

$$E_0 = E_{ref}\left\{0.5B_1 + 0.25B_2 + \cdots + \left(2^n\right)^{-1}B_n\right\}$$

Where E_0 is output voltage; E_{ref} is reference voltage; B_n is status of successive bits in the binary register

  - Data Holding that changes series of discrete analogue signals into one continuous signal

Example

- A DAC has a reference voltage of 100 V and has 6-bit precision. Three successive sampling instances 0.5 sec apart have the following data in the data register:

Instant	Binary Data
1	101000
2	101010
3	101101

- Output Values:

E_{01} = 100{0.5(1)+0.25(0)+0.125(1)+0.0625(0)+0.03125(0)+0.015625(0)}

E_{01} = 62.50V

E_{02} = 100{0.5(1)+0.25(0)+0.125(1)+0.0625(0)+0.03125(0)+0.015625(0)}

E_{02} = 65.63V

E_{03} = 100{0.5(1)+0.25(0)+0.125(1)+0.0625(0)+0.03125(0)+0.015625(0)}

E_{03} = 70.31V

Input/Output Devices

Binary data:

- Contact input interface – input data to computer
- Contact output interface – output data from computer

Discrete data other than binary:

- Contact input interface – input data to computer
- Contact output interface – output data from computer

Pulse data:

- Pulse counters - input data to computer
- Pulse generators - output data from comp

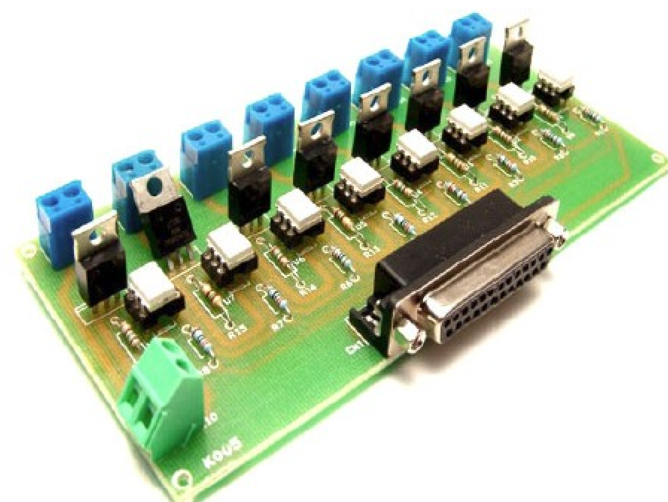


photo may look different that original circuit