Chapter 1

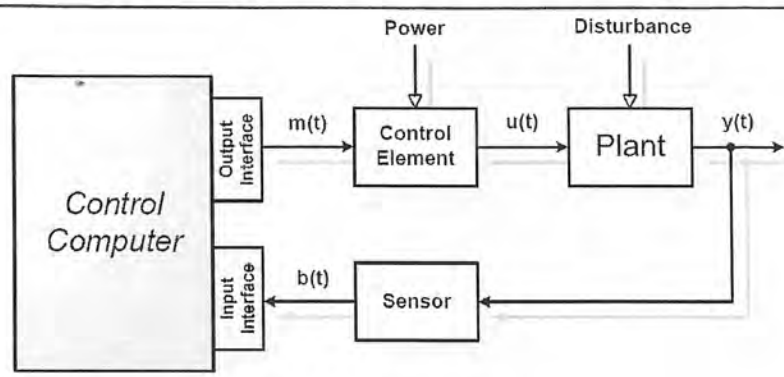
1.1 Classification of Control Systems

- Continuous-time Control
  - Mostly referred to as *"Analog Control"*
  - Controller takes *corrective* action *continuously* in time.
  - Analog circuit elements are used to implement such controllers.
- Discrete-time Control
  - Also known as *"Digital- or Numerical Control"*
  - Corrections take place at particular *instances* in time.
    - Controller's output stays constant between these instances.
  - Microprocessors are generally employed to realize these controllers.
- Hybrid Control
  - A *blend* of both control systems (and strategies).

1.2 Discrete-time Control Applications

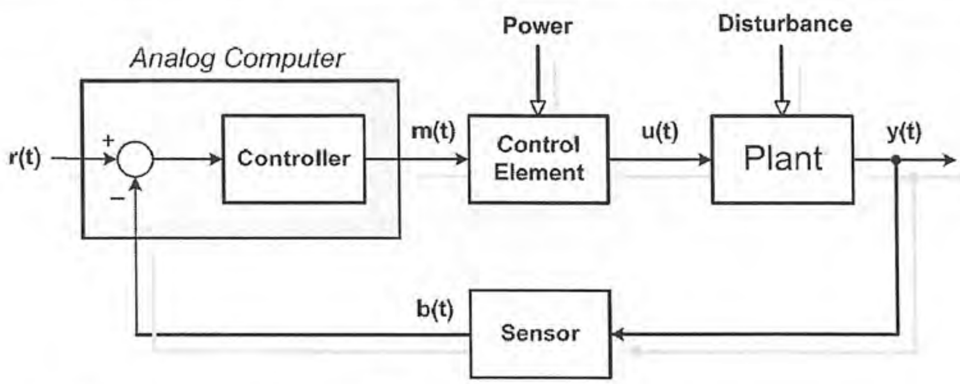
- Home appliances
  - Dishwasher
  - Washing machine
  - Fridge
- Robotics
  - Mobile robots
  - Industrial robots
- Automations systems
  - Factory automation
- Aerospace applications
  - Aircraft control / guidance
  - Satellites
  - Rocket / missile guidance
- Millitary applications
  - Advanced weapons systems
  - Radar systems
- CNC Machine Tools
- Electric Motor Drivers
- Consumer goods
  - TV sets
  - CD / DVD players / recorders
  - Camcorders
  - Mobile phones
- Personal Computing
  - Hard disk drives
  - CD-RW drives

1.3 Typical Digital Control System



- Function of control computer:
  - Computation of correction signal
  - Generating command / reference
  - Decision making
  - Implementation of complex logical operations.

1.4 Typical Analog Control System



- Function of analog computer:
  - Analog filtering of the measurement noise in the input signals
  - Comparison of the measurement (b) and the command (r)
  - Generation of correction signal (m) on a continuous basis.

Comparison

Analog Control	Digital Control
Control computations (such as ∫dt, d/dt, ×, ÷, ±, etc.) are continuous in time.	All computations are performed in distinct time intervals.
Op-amps are used as computing elements.	μPs, DSPs, μCs, PLCs are commonly utilized.
Hardwired – Not suitable for reconfiguration.	Flexible / easily programmed.
Very sensitive to measurement- and process noise.	Somewhat sensitive to signal conversion errors, quantization noise, and round-off / truncation errors.
Inexpensive for simple control systems but can be quite costly for complex systems.	Hardware is inexpensive but control software development tools can be expensive.

1.5 Digital Control Systems vs. Analog Control Systems

- **Better precision and computational capabilities**
  - More complex control algorithms
- **Improved flexibility**
  - Different operating conditions can be managed by just changing the software
- **Better reliability and repeatability**
  - No fatigue, thermal drift etc.
- **Digital signals can be easily transmitted**
  - Digital signals are more robust than analog ones with respect to noise and disturbances

- **A more difficult design process**
  - The designer must possess competences in the field of electronics and digital interfaces
- **Weaker stability**
  - Transmission discontinuities, delays
  - The choice of the sampling time is important
- **Undesired and unmanaged system failures**
  - It is difficult to consider and evaluate all the possible failures during the software design
- **Electric power is always needed**

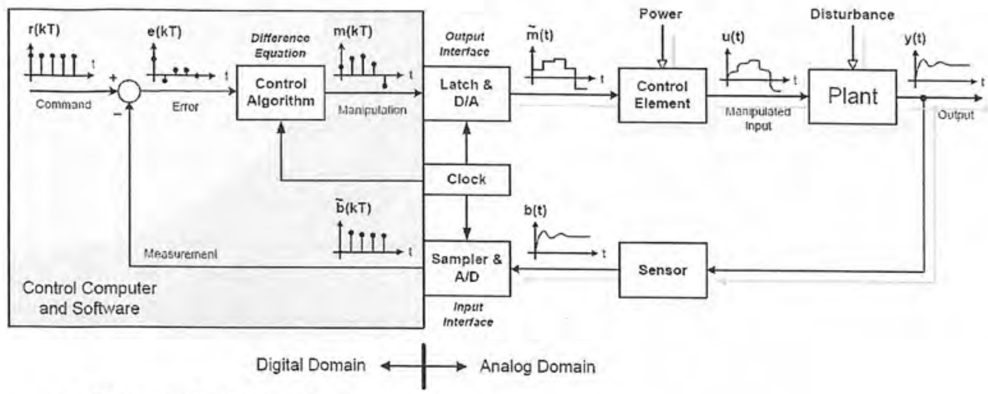
1.6 Properties of Digital Control Systems

- All physical quantites are represented by corresponding (binary) numbers with finite length.
- All computations are synchronized and are carried out periodically.
- The period in which all these computations are performed is called *sampling period* (T).

- All quantites in discrete-time domain could be expressed as
  - $X(t = kT) \equiv X(k)$ where $k \in \{0, 1, 2, \ldots\}$
  - k is called *time index*.
- Control algorithm is essentially an algeabric expression (*difference equation*) which depends on not only the history of error but also that of the manipulation):

$$m(k) = -\sum_{i=1}^{N} a_i \cdot m(k-i) + \sum_{j=0}^{M} b_j \cdot e(k-j)$$

1.7 A General Digital Control System



- Control elements:
  - Motor Driver + Electric Motor
  - Servo-valve + Hydraulic Cylinder / Motor
  - Power Converter + Electric Heater

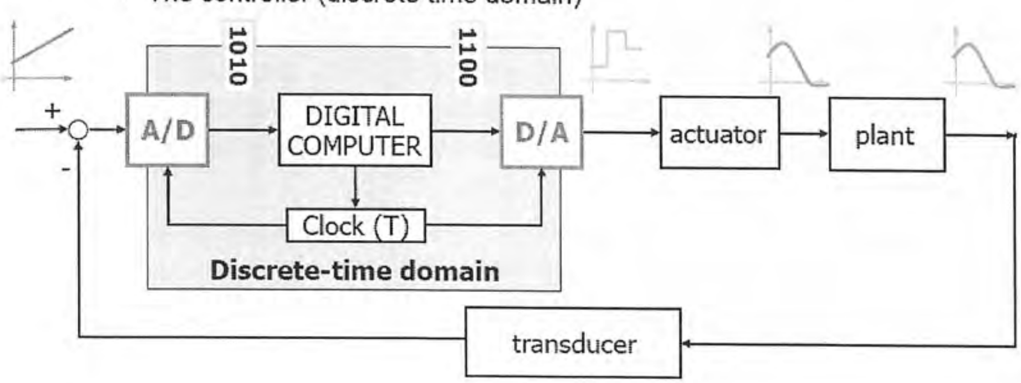
Or

Digital Control Systems

Digital Control Systems

✓ A computer is present in the control loop:
  - ✓ The control action is computed in the discrete-time domain with period T

✓ Suitable interfaces are needed between:
  - ✓ The plant (continuous time domain)
  - ✓ The controller (discrete time domain)



Digitization

- The difference between the continuous and digital systems is that the digital system operates on samples of the sensed plant rather than the continuous signal and that the control provided by the digital controller D(s) must be generated by algebraic equations.
- In this regard, we will consider the action of the analog-to-digital (A/D) converter on the signal. This device samples a physical signal, mostly voltage, and convert it to binary number that usually consists of 10 to 16 bits.
- Conversion from the analog signal $y(t)$ to the samples $y(kt)$, occurs repeatedly at instants of time T seconds apart.
- A system having both discrete and continuous signals is called sampled data system.
- The sample rate required depends on the closed-loop bandwidth of the system. Generally, sample rates should be about 20 times the bandwidth or faster in order to assure that the digital controller will match the performance of the continuous controller.

Digital Control System

- Analog electronics can integrate and differentiate signals. In order for a digital computer to accomplish these tasks, the differential equations describing compensation must be approximated by reducing them to algebraic equations involving addition, division, and multiplication.
- A digital computer may serve as a compensator or controller in a feedback control system. Since the computer receives data only at specific intervals, it is necessary to develop a method for describing and analyzing the performance of computer control systems.
- The computer system uses data sampled at prescribed intervals, resulting in a series of signals. These time series, called sampled data, can be transformed to the *s*-domain, and then to the z-domain by the relation $z = e^{zt}$.
- Assume that all numbers that enter or leave the computer has the same fixed period *T*, called the sampling period.
- A sampler is basically a switch that closes every *T* seconds for one instant of time.