**SIGNALS**

A *continuous-time* signal is a signal defined over a continuous range of time. The amplitude may assume a continuous range of values or may assume a finite number of distinct or quantized values. An *analog* signal is one where both the amplitude and time are continuous.

An *discrete-time* signal is a signal defined only at discrete instants of time i.e. \( t \) is quantized. If the amplitude can assume a continuous range of values, then the signal is called a *sampled-data* signal, as it can be generated by sampling an analog signal. A *digital* signal is a discrete-time signal with quantized amplitude. Such a signal can be represented by a sequence of numbers.

![Continuous-time analog signal](image1.png)
![Continuous-time quantized signal](image2.png)

![Sampled-data signal](image3.png)
![Digital signal](image4.png)

(a) Continuous-time analog signal; (b) continuous-time quantized signal; (c) sampled-data signal; (d) digital signal.

**SYSTEMS**

*Discrete-time* control systems are control systems in which one or more variables can change only at discrete instants of time. These instants will be denoted by \( kT \) or \( t_k \) \((k = 0, 1, 2, \ldots)\).

We will be dealing mainly with linear, time-invariant discrete-time systems, which can be described by *linear difference equations*. The general form of an *nth*-order linear difference equation is:

\[
x(k) = \alpha_n e(k) + \alpha_{n-1} e(k-1) + \cdots + \alpha_0 e(k-n) - \beta_{n-1} x(k-1) - \cdots - \beta_0 x(k-n)
\]

The solution of difference equations may be approached by using the z-transform.
Advantages over analog control:

1. Data processing is straightforward.
2. Control programs (controller characteristics) can be easily changed.
3. Less problems due to internal noise and drift effects.

Disadvantages:

1. The sampling and quantizing process tend to result in more errors, which degrade system performance.
2. Designing to compensate for such degradation is more complex.

A more detailed block diagram of a digital control system:
Types of Sampling

1. Periodic. \( t_k = kT \ (k = 0, 1, 2, \ldots) \), gives equally spaced samples.

2. Multi-order sampling. The pattern of the \( t_k \)'s is repeated periodically.

3. Multi-rate. Different sampling rates used throughout the system.

4. Random. \( t_k \) is a random variable.

- Generally, periodic sampling will be used.

Selection of sampling rate

*Sampling theorem:* if a continuous-time signal is bandlimited or contains no frequency components higher than \( w_c \), then theoretically the original signal can be reconstructed without distortion if it is sampled at a rate of at least \( 2w_c \).

In practice, the sampling frequency is chosen to be much higher the \( 2w_c \), usually 8-10 times \( w_c \).

*Note:* the sampling frequency affects the stability of a closed-loop digital control system.