Ministry of Higher Education and Scientific Research
Al-Mustaqbal University
Medical Instrumentation Techniques Engineering Department

Subject: Digital Signal Processing

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Lecture1: Introduction

Class: 3rd

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1.1. Introduction

Digital Signal Processing (DSP) is a branch of electrical engineering and computer science that focuses on analyzing, modifying, and interpreting signals. These signals can be audio, video, sensor data, or other forms of information. The key feature of DSP is that it works with signals in digital form—this means the signals are represented as sequences of numbers, making them easier to manipulate using computers or specialized hardware.

What is a Signal?

A **signal** is any time-varying physical phenomenon that carries information. Signals can come from a variety of sources:

- **Audio signals** (e.g., speech or music)
- **Video signals** (e.g., images or video frames)
- **Biological signals** (e.g., EEG, ECG from medical equipment)
- **Sensor data** (e.g., temperature, pressure readings)

For Example, Cardiogram Signal

A **cardiogram signal**, more commonly known as an **electrocardiogram (ECG or EKG) signal**, represents the electrical activity of the heart as a function of time. This signal is recorded using electrodes placed on the skin as shown in figure 1.

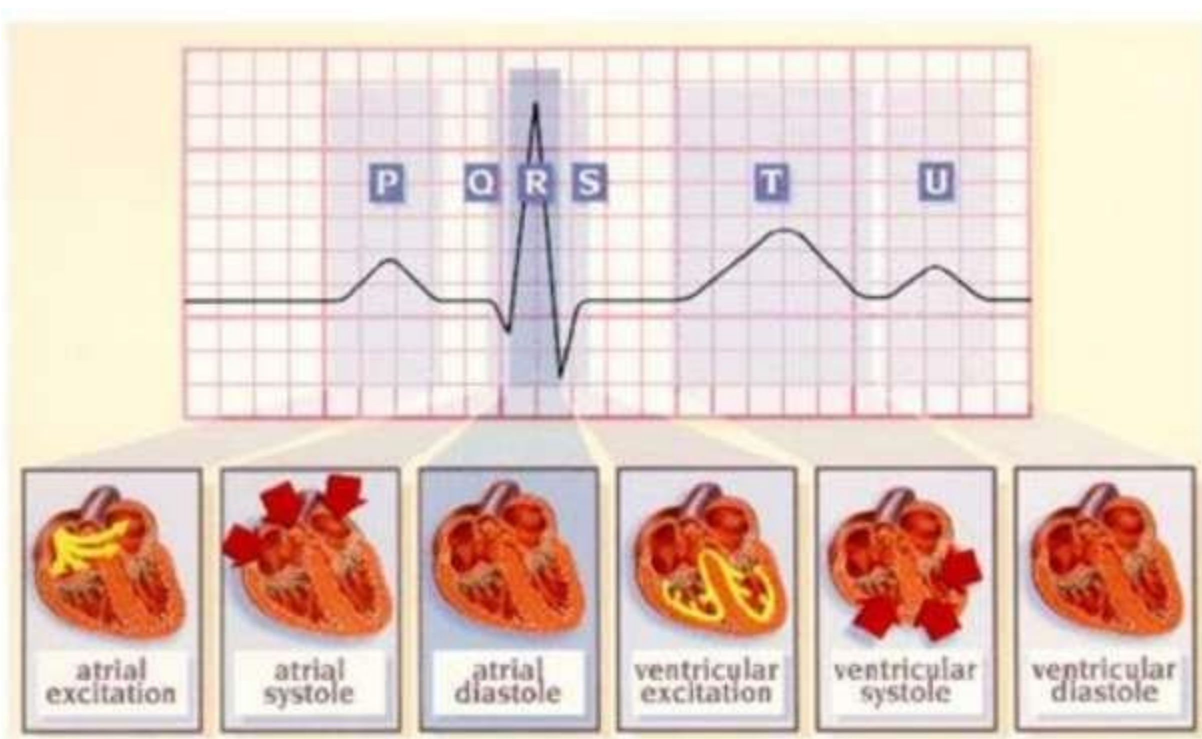


Fig.1: Cardiogram signal

1.2. Block Diagram of DSP

The **block diagram of Digital Signal Processing (DSP)** illustrates the fundamental steps involved in converting an analog signal into a digital signal, processing it digitally, and converting it back into an analog signal as shown in figure 2.

1. **Analog Signal**: This is the continuous-time signal (e.g., audio, temperature, pressure) that needs to be processed digitally.

2. **Analog-to-Digital Converter (ADC):**
   - Sampling: The continuous analog signal is sampled at specific intervals, converting it into a sequence of discrete values.
   - Quantization: The sampled values are mapped to the nearest discrete level.
   - Encoding: The quantized values are converted into binary numbers (bits) for digital processing.

3. **Digital Processing:** In this stage, various operations such as filtering, transformation, and analysis are performed on the digital signal. Some common DSP operations include:
   - Filtering: Removing unwanted components or noise from the signal.
   - FFT (Fast Fourier Transform): Converting the signal from the time domain to the frequency domain for analysis.
   - Compression: Reducing the size of the signal for efficient storage or transmission.

4. **Digital-to-Analog Converter (DAC)**: After the digital signal is processed, it may be converted back into an analog signal. The DAC performs the reverse of the ADC by reconstructing a continuous-time signal from the digital data.

5. **Analog Output:** The reconstructed analog signal is then output to devices like speakers, monitors, or other analog systems for further use.

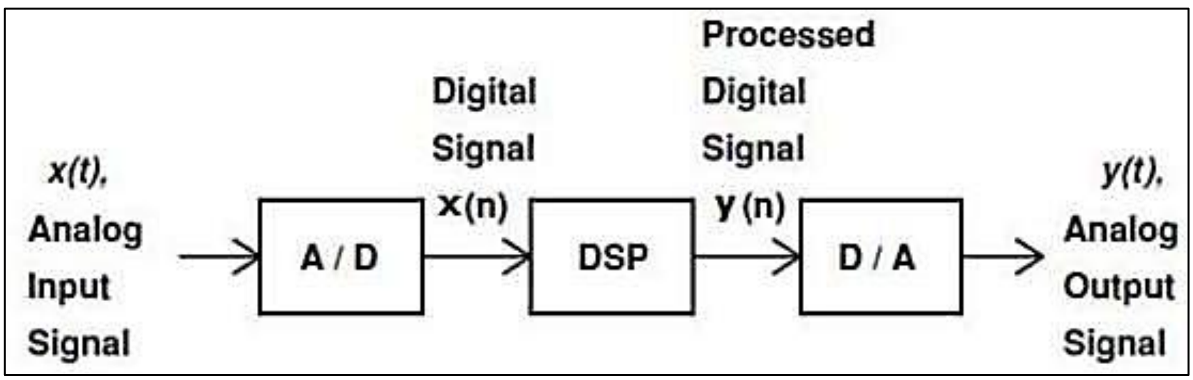


Fig.2: Block diagram of signal processing system.

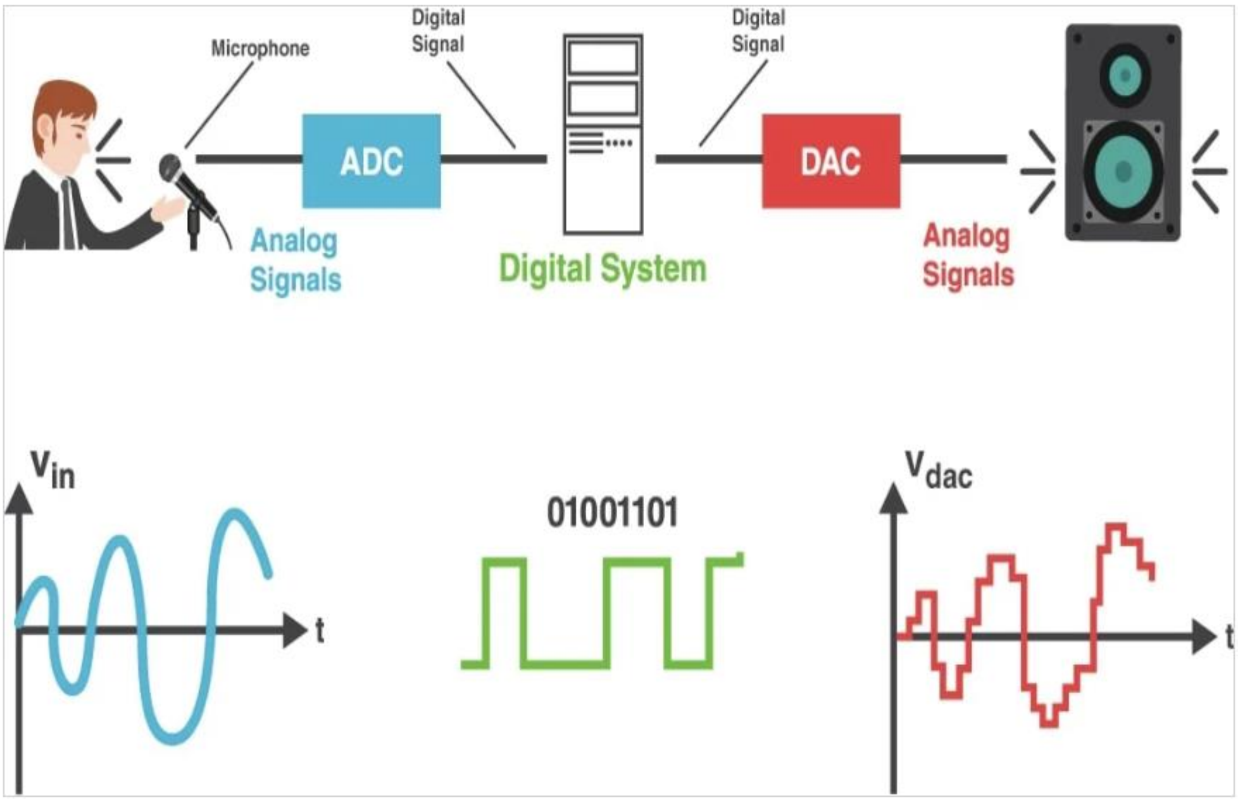


Fig.3: depicts an audio processing application.

1.3. Digital Signal Processing (DSP) vs Analog Signal Processing (ASP)

DSP: Signals are converted from analog to digital through sampling and quantization, then processed using digital devices and algorithms. The digital signal consists of discrete values (bits) that represent data.

- Provides high accuracy.
- Highly flexible.
- DSP systems can be more expensive.
- Less affected by noise and interference.
- Digital signals are discrete time signals.

ASP: Signals are processed continuously in their original analog form, without converting them too digitally. The analog signal is a continuous waveform that represents data.

- Less accurate
- Less flexible
- Lower cost
- Analog signals are more susceptible to noise and environmental interference.
- Analog signals are continuous time signals.

1.4. DSP Applications

1. Audio and Speech Processing
   - Noise Reduction
   - Audio Compression
   - Voice Recognition

2. Image and Video Processing
   - Image Compression
   - Video Encoding
   - Image Enhancement

3. Telecommunications
   - Modulation and Demodulation
   - Error Detection and Correction
   - Speech Coding

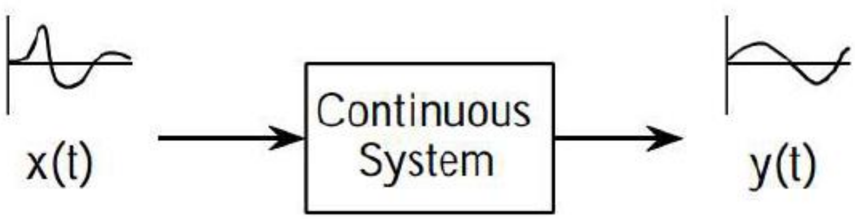
4. Biomedical Signal Processing
   - ECG/EEG Signal Processing
   - Medical Imaging
   - Wearable Health Devices

5. Control Systems and Robotics
   - Adaptive Filtering
   - Motor Control

1.5. Classification of Signals

The signals can be classified into two parts depending upon independent variable (time).

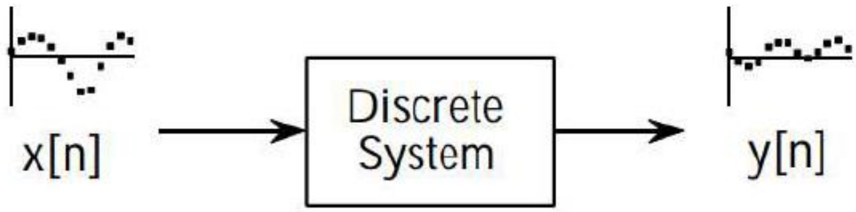
1) **Continuous Time signals:** A continuous time signal is a signal that is defined for every moment in time meaning it has a value at every instant. The special characteristic of analog signals is that they are continuous in amplitude.



2) **Discrete time signals** are a function x[n] where n is an integer representing discrete time indices. Mathematically, a discrete-time signal can be represented as x[n]:

Where,
x is the signal name,
n is the discrete time index (an integer), $-\infty<n<\infty$

The discrete time signals are obtained by time sampling of continuous time signals.



The discrete time signals are obtained by time sampling of continuous time signals, such as speech, with an analog to-digital (A/D) converter. For example, a continuous-time signal $xa\ (t)$ that is sampled at a rate of $fs = 1/T$ samples per second produces the sampled signal $x(n)$, which is related to $xa\ (t)$ as follows:

$$x(n) = x_a\ (nT)$$

1.6. Standard of Discrete Time Signals (sequences)

1) Unit Impulse

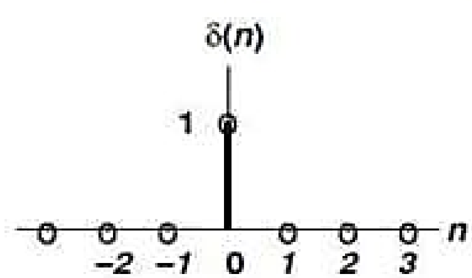
The unit impulse function, denoted as $\delta[n]$, is defined as:

$$\delta(n) = \begin{cases} 1 & \text{if } n = 0 \\ 0 & \text{if } n \neq 0 \end{cases}$$

This is the formal definition of the discrete-time unit impulse function. It indicates that the value of the impulse is 1 only at n=0, and 0 everywhere else.

$$\delta(n) = \{\ldots, 0, 0, 0, 1, 0, 0, 0, \ldots\}$$

This is the sequence form, showing a list of values for the function. The impulse function is 0 for all values of n, except at n=0 where it takes the value 1.



2) Unit Step

The unit step signal is one of the most fundamental signals defined as:

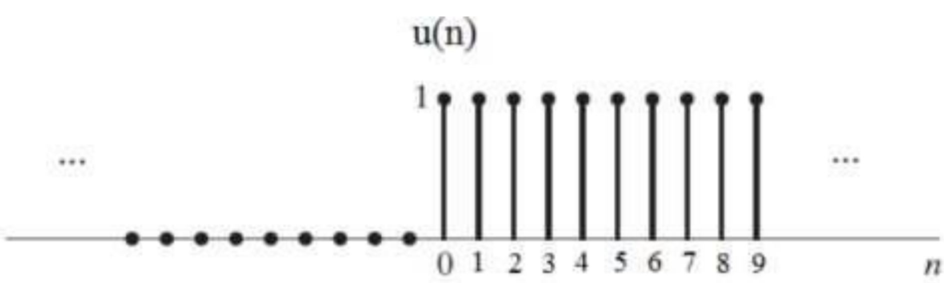
$$u(n) = \begin{cases} 1 & \text{if } n \geq 0 \\ 0 & \text{if } n < 0 \end{cases}$$

- For $n \geq 0$: The signal takes a value of 1.
- For $n < 0$: The signal is 0.

Example:

u(n)= {0,0,0,1,1,1, 1,…}

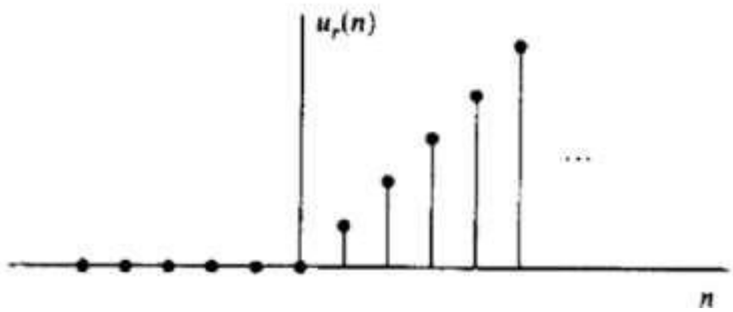
The signal is 0 for $n < 0$, and for $n \geq 0$, it takes the value 1.



3) Unit Ramp

The unit ramp function in discrete time is defined as:

$$u_r(n) = \begin{cases} n, & n \geq 0 \\ 0, & n < 0 \end{cases}$$



Example:

For n=−2, −1,0,1,2,3, …

$u_r(n)$= {0,0,0,1,2,3,4, …}

- For n=−2, $u_r(-2)$=0
- For n=0, $u_r(0)$=0
- For n=1, $u_r(1)$=1
- For n=2, $u_r(2)$=2

4) Exponential Signal

An exponential discrete-time signal can be represented as:

$$x(n) = a^n \quad \text{for } n \geq 0$$

Where **a** is a constant. For example, if a=0.5:

$$x(n) = 0.5^n = \{1, 0.5, 0.25, 0.125, \ldots\} \quad \text{for } n = 0, 1, 2, \ldots$$

Q\ Which one of the following signals represents a discrete time signal?

a- $x(t) = 2t$.
b- $x(t) = 2t+1$.
c- $x(n) = n+1$.
d- $x(t) = t^2$.

Solve:

The correct answer is:

c- x(n) = n + 1. Discrete-time signals are defined only at integer values of n.