Lecture Note: Introduction to Signals and Systems

1. Motivation and Relevance

Signals and systems form the foundation of many modern engineering applications, particularly in **autonomous vehicles (AVs)**.

- Autonomous vehicles rely on **high-quality sensors** to gather information from the environment.
- These sensors produce **signals**, which are processed for:
  - **Perception**
  - **Control**
  - **Decision-making**
- Similar to humans using senses (e.g., vision while driving), AVs interpret environmental data through signals to take actions.

2. Learning Objectives

By the end of this lecture, students should be able to:

- Understand fundamental concepts of **signals and systems**
- Classify signals as:
  - Continuous-time
  - Discrete-time
- Identify real-world examples of signals
- Distinguish between:
  - Noise
  - Disturbances
- Explain what a **system** is and how signals interact with systems

3. What is a Signal?

Definition

A **signal** is any quantity that **changes over time or space** and carries information.

Mathematical Representation

- A signal is expressed as a function:
  - $x(t)$: signal as a function of time
  - Can depend on multiple variables (e.g., time and space)

Examples of Signals

Signals are everywhere in daily life:

- Temperature variation over time
- Traffic flow on highways
- Human voice (sound waves)
- Light intensity (e.g., traffic signals)
- Wind speed vs. height

Role in Autonomous Vehicles

Signals provide critical environmental information such as:

- Camera images
- LiDAR point clouds
- Radar signals
- Vehicle speed, acceleration, and position (GPS)

4. Types of Signals

4.1 Continuous-Time Signals (Analog Signals)

- Defined at **every instant of time**
- Represented as $x(t)$
- Examples:
  - Voltage
  - Sound waves

Key Property:

- Infinite number of values within any time interval

4.2 Discrete-Time Signals

- Defined only at **specific time instants**
- Example:
  - Weekly stock market values

Key Idea:

- Signal values exist only at sampled times (not continuous)

4.3 Digital Signals

- A special type of discrete signal
- Amplitude values are limited to:
    - **0 or 1**

Importance:

- Used by computers and processors
- All real-world signals must be converted to digital form for processing

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5. Signal Processing in Systems

- Real-world (analog) signals → converted to **digital signals**
- Digital processing occurs in:
    - Microcontrollers
    - CPUs
- Output is converted back to analog form if needed

6. Periodic Signals

Definition

A signal is **periodic** if it repeats after a fixed time period T:

$$x(t) = x(t + T)$$

Types

- Continuous-time periodic signals
- Discrete-time periodic signals

Frequency

- Number of cycles per second

$$f = \frac{1}{T}$$

- Measured in **Hertz (Hz)**

7. Noise and Disturbances

7.1 Noise

- **Unwanted signal** that corrupts useful information

Sources:

- Sensor noise
- Electronic circuit noise
- Quantization noise (during analog-to-digital conversion)

Impact:

- Reduces accuracy of perception and estimation

7.2 Disturbances

- **External unwanted influences** affecting system behavior

Examples:

- Weather (rain, fog, snow)
- Road conditions (potholes)
- Wind forces
- Unexpected actions by other vehicles or pedestrians

Comparison

Aspect	Noise	Disturbance
Source	Internal	External
Example	Sensor error	Weather, road conditions
Effect	Data corruption	System behavior change

8. Impact on Autonomous Systems

- Noise and disturbances can:
    - Degrade perception accuracy
    - Affect control decisions
    - Reduce system performance

Engineering Solutions

- Filtering techniques
- Robust control design
- Feedback (closed-loop) systems
- High-quality sensors

9. Key Takeaways

- Signals represent **information** about the environment.
- Systems **process signals** to produce meaningful outputs.
- Signals can be:
  - Continuous
  - Discrete
  - Digital
- Real-world engineering systems must handle:
  - Noise (internal)
  - Disturbances (external)
- These concepts are essential for **autonomous vehicle perception and control**.

10. Preview of Next Topics

Future lectures will cover:

- Sensor technologies
- Control systems
- Communication systems in autonomous vehicles