Introduction to Signals and Systems

For Autonomous Transportation

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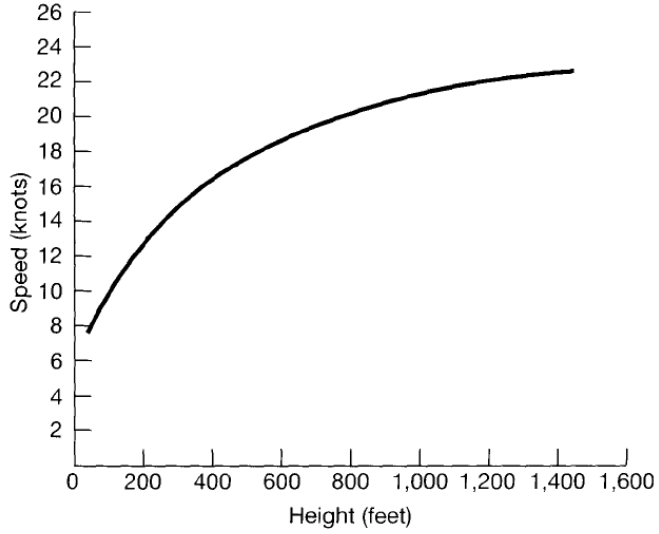
Learning Objectives

- **Define** fundamental concepts of **signals and systems**, with examples drawn from transportation and autonomous vehicles
- **Classify signals** as continuous-time, discrete-time, digital, and periodic, and explain their relevance in engineering applications
- **Identify real-world signals** used in autonomous transportation systems
- **Differentiate** between **noise** and **disturbances**, and discuss their impact on sensing, perception, and control in autonomous vehicles
- **Explain what a system is** and describe how systems transform input signals into output signals
- **Describe the role of signals and systems** in autonomous vehicles

What is a Signal?

- A **signal** is information that changes over time or space. Signals are represented mathematically as functions of one or more independent variables.
- Signals examples in daily life:
  - Temperature throughout the day
  - Traffic volume on a highway
  - Your voice when speaking
  - Light intensity from a traffic signal



Annual vertical wind profile.

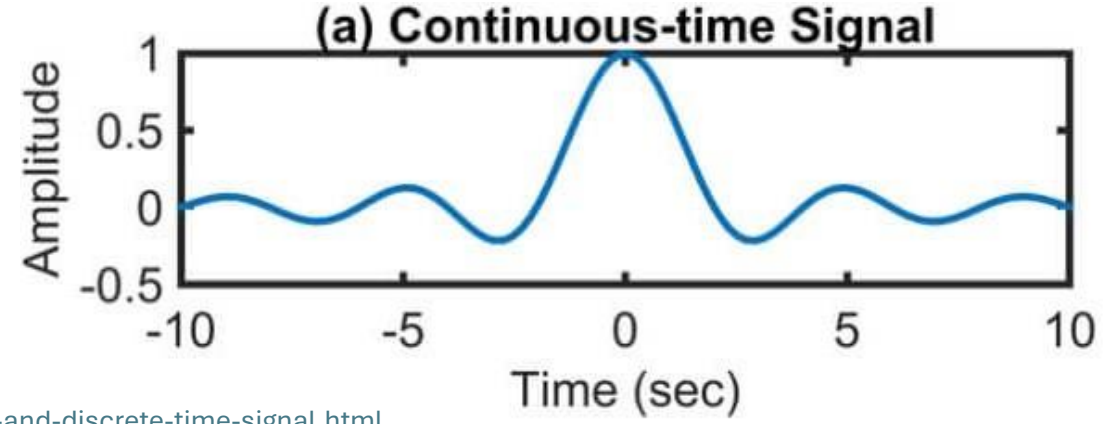
- In autonomous vehicles, signals carry crucial information about the environment.

Signals in Autonomous Vehicles:

- Camera Images
- LiDAR Point Clouds
- Radar Returns
- Vehicle Speed and Acceleration
- GPS Position

Types of Signals (Continuous-Time):

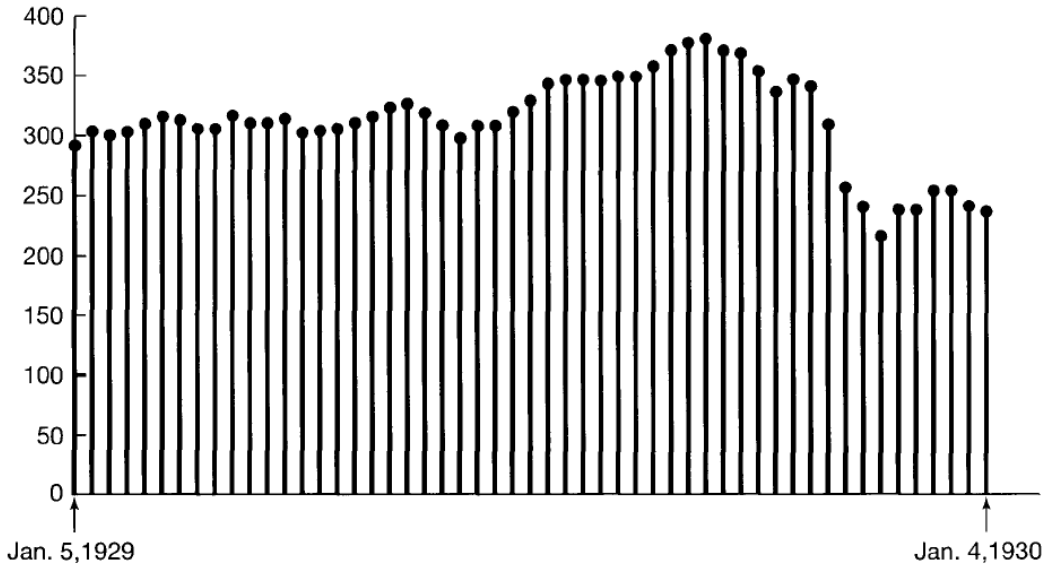
- **Continuous-time Signal (Analog Signal)** is a physical quantity, such as voltage or sound, that is defined for every instant of time t within a specific range. Represented as $x(t)$, it is a smooth and analog function where the independent variable t is continuous, and thus the signal is defined for a continuum of values of the independent variable.



https://studyelectrical.com/2023/03/continuous-time-signal-and-discrete-time-signal.html

Types of Signals (Discrete-Time):

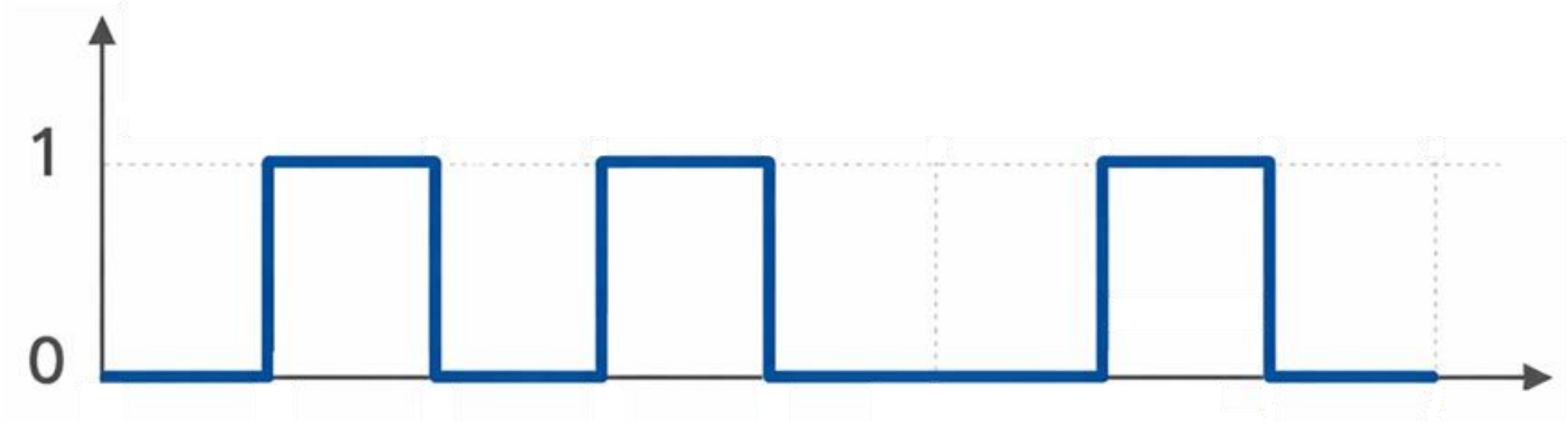
- **Discrete-time Signals:** The discrete-time signals are defined only at discrete-times, and consequently for theses signals, the independent variable takes on only a discrete set of values.



Weekly Dow-Jones Stock Market index.

Digital Signals:

- **Digital signals** are discrete-time signals with discrete amplitude levels, typically represented using 0s and 1s. Examples are computer data and GPS coordinates.

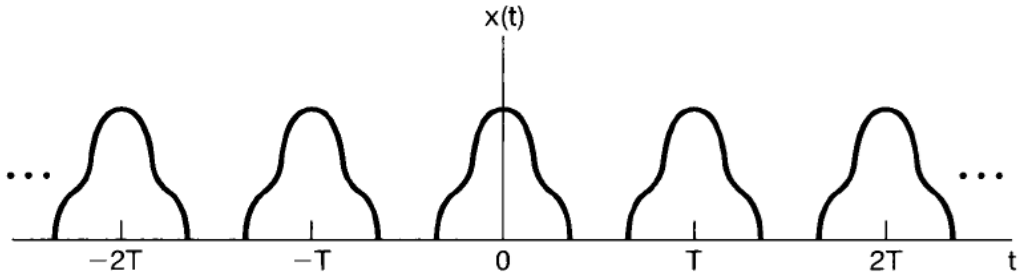


Periodic Signals:

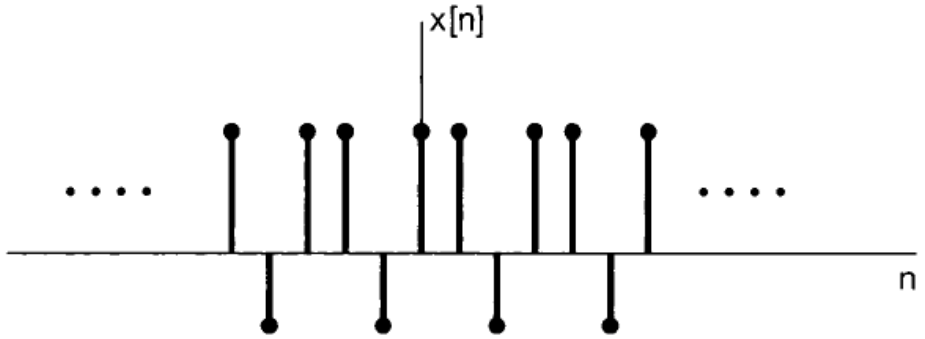
- A periodic signal is a signal that repeats itself exactly after a fixed period of time.

  Mathematically, a periodic continuous-time signal $x(t)$ with the *period T (in seconds)* has the property that $\boldsymbol{x(t) = x(t + T).}$

- Frequency (f) of a periodic signal is the number of cycles per second measured in Herz (*Hz*), represented by $f = \frac{1}{T}$



A continuous-time periodic signal.



A discrete-time periodic signal.

Noise :

- **Noise** is any **unwanted signal** that corrupts or distorts useful information such as camera pixel noise and LiDAR measurement error. Common sources of noise in autonomous transportation:
  - Sensor noise (camera pixel noise, LiDAR measurement error)
  - Electronic noise in circuits
  - Quantization noise from analog-to-digital conversion
- **Why this matters:**
  - Noise can cause incorrect perception or estimation

Disturbance :

- **Disturbances** are **external influences** that affect system behavior. Common disturbances:
  - Weather effects (rain, fog, snow)
  - Road irregularities (bumps, potholes)
  - Wind forces acting on the vehicle
  - Other vehicles and pedestrians
- **Why this matters:**
  - Disturbances can degrade control system performance

What is a System?

- A system is a set of connected components that takes an input signal, act on it, and produces an output signal. Examples: **A light switch is a system.** The input is the switch position (ON or OFF), and the output is the light (ON or OFF). **A volume knob is a system.** The input is an audio signal, and the output is the same signal but louder or quieter. **A camera** (system) receives light (input) and produces an image (output)

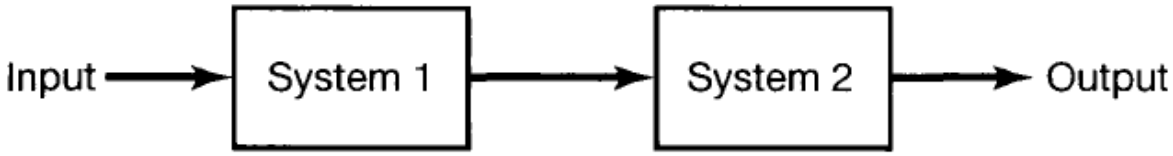
Systems in Autonomous Vehicles:

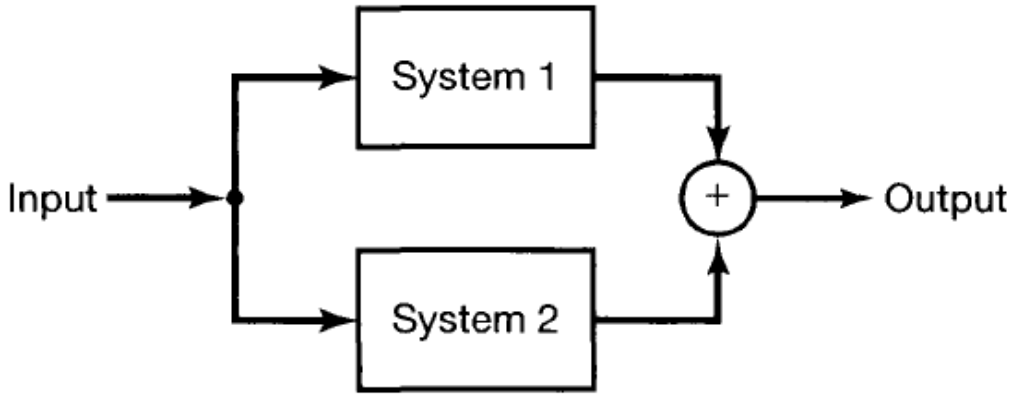
- Perception System
- Control System
- Communication System
- Planning System

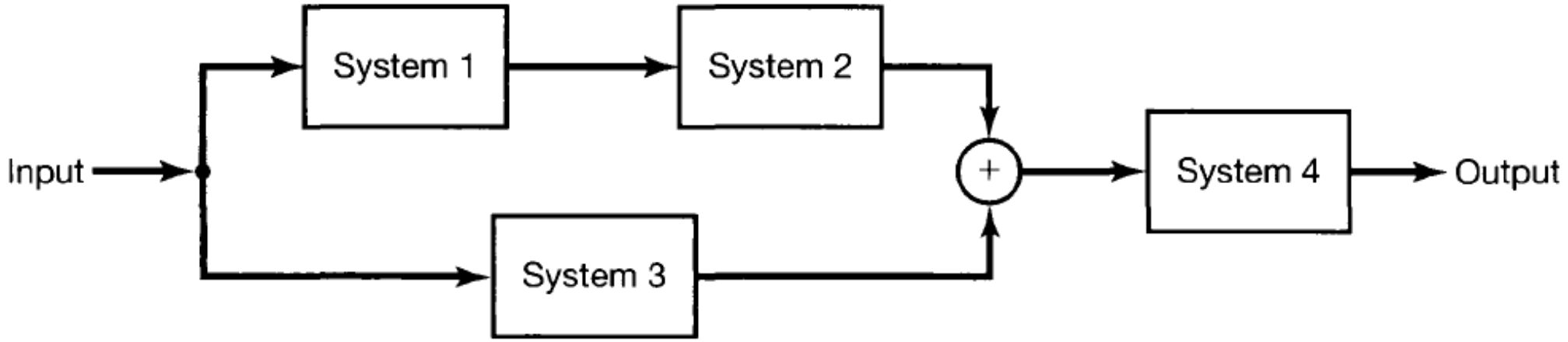
Interconnections of Systems

- **Many real-world systems are made up of interconnected subsystems that work together.**
- For example, a digitally controlled aircraft combines the aircraft dynamics, sensors, a digital autopilot, and actuators. Sensors measure the aircraft's motion, the autopilot processes this information and pilot commands, and the actuators adjust the control surfaces to control the aircraft

Interconnections of Systems







References

[1] Oppenheim, A. V., Willsky, A. S., & Nawab, S. H., *Signals and Systems*, 2nd ed. Upper Saddle River, NJ, USA: Prentice Hall, 1997.