CSE435 – Robotics

Lecture 4 Notes

Topic: Sensors for Mobile Robots

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1. Sonar (Ultrasonic) Sensor

Principle

- Emits short acoustic signals (~1 ms) at ultrasonic frequencies between **50 kHz – 250 kHz**.
- Measures the time from signal emission until the echo returns to the sensor — known as **Time of Flight (ToF)**.

  Time of Flight = 2 × Distance to nearest obstacle

- If no echo is received within a specified time window, it indicates **no nearby obstacle**.

Disadvantages

1. **Narrow Detection Cone:**
   - Each sensor covers only a small angular range.
   - Multiple sensors (e.g., 24 spaced at 15° each) are required for full 360° coverage.
2. **Interference:**
   - One sensor's signal can be received by another nearby sensor.
3. **Reflection Errors:**
   - Angled surfaces cause reflections that make obstacles appear **farther away** than they actually are.

Current Alternatives

- Sonar sensors are now largely replaced by **laser** or **infrared (IR)** sensors.
- **Laser sensors** are more accurate but typically **heavier, larger, and more expensive**, making them less suitable for small mobile robots.

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2. Infrared (IR) Sensor

Principle

- Uses a **pulsed infrared LED** (typically at 40 kHz) and a **detection array**.
- The **angle of reflection** of the IR beam varies with the **distance to the object**.

Why IR Sensors Don't Use Time-of-Flight

- The **speed of light** is extremely high, so the ToF would be **too short** to measure accurately with low-cost, small sensors.

Types of IR Light Detectors

1. **IR Detector Cards**
2. **IR-Sensitive Cameras**

Common IR Sensor Models

Model	Output Type	Description
Sharp GP2D12	Analog	Voltage output varies with distance
Sharp GP2D02	Digital (serial)	8-bit serial output triggered by a CPU clock signal

> [!Note] The GP2D02 sensor transmits an 8-bit distance value over a single data line, synchronized by a clock signal from the CPU.

Sensor Output Behavior

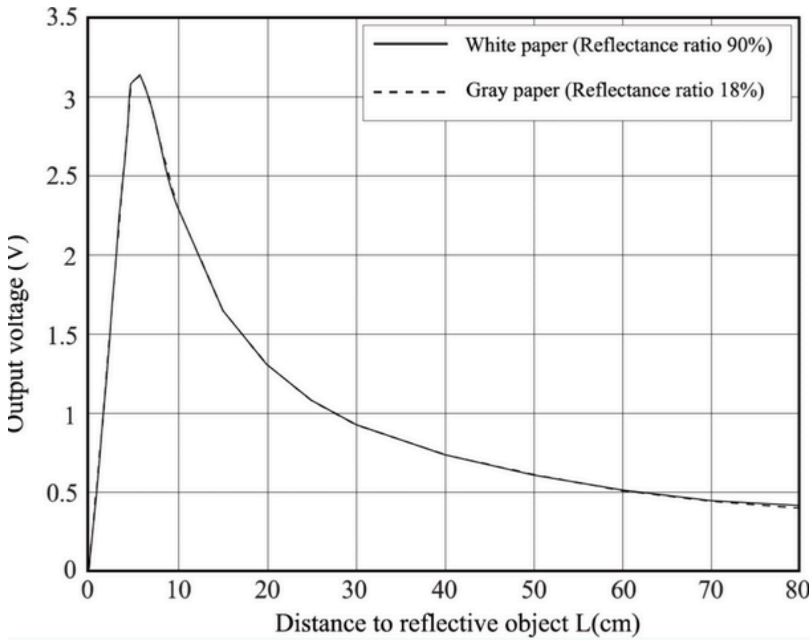

Figure 1: IR Sensor Output Voltage vs. Distance

Challenges

1. **Nonlinearity:**
   - The voltage–distance relationship is nonlinear.
   - Requires a **lookup table (LUT)** (e.g., 256 entries for an 8-bit sensor), calibrated per sensor.
2. **Ambiguity at Close Range:**
   - Distances below ~6 cm may yield **duplicate output voltages**.
   - To prevent this, mount the sensor so obstacles cannot approach closer than 6 cm.

IR Proximity Sensors

- Simpler than Position Sensitive Detector PSD-type sensors.
- **Binary output (0 or 1)** — acts like a **tactile sensor** that detects the presence or absence of an object.

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3. Compass Sensor

Self-Localization

Determining a robot's **position and orientation** in its environment.

Dead Reckoning Method

- Uses **shaft encoders** on the wheels:

    1. One encoder per wheel.
    2. Start from a known position and orientation.
    3. Integrate all movements to estimate current position.

> [!Caution] Wheel slippage causes cumulative errors — position estimates become increasingly inaccurate over time.

Improved Methods

- Use a **compass sensor** for **absolute orientation**.
- Combine with **GPS** for **global position tracking**.

Compass Types

Type	Description
Analog Compass	8-direction output represented by voltage levels
Digital Compass	High resolution (~1° accuracy)

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4. Accelerometer and Gyroscope Sensors

Overview

- Together called **Inertial Sensors** or **Inertial Trackers**.
- Modern designs use **Micro-Electro-Mechanical Systems (MEMS)** technology.
- Used to measure **orientation**, **acceleration**, and **angular velocity**.

Applications

- Orientation tracking for:
    - Tracked robots
    - Balancing robots
    - Walking robots
    - Autonomous aerial robots

> [!Note] Typically, **multiple sensors** (2 or 3 of the same model) are combined to measure multi-axis motion.

Sensor Categories

Sensor	Function	Example Models	Output Type
Accelerometer	Measures linear acceleration along one axis	ADXL05 (1-axis), ADXL202 (2-axis)	Analog / PWM
Gyroscope	Measures angular velocity about one axis	HiTec GY130 Piezo Gyro	PWM

Inclinometer	Measures absolute tilt angle about one axis	Seika N3, N3D	Analog / PWM

How They Work

- **Accelerometer:** Measures acceleration (**a**) along X, Y, Z.
- **Gyroscope:** Measures angular velocity (**ω**) around X, Y, Z.
- Combined, they form a **complete inertial measurement unit (IMU)**.

Integration Principle

- Gyroscope data (ω) is **integrated over time** to find **orientation angle (θ)**.
- Accelerometer data (a) is **double-integrated** to determine **position**, after compensating for **gravity**.

Digital Implementation

- Integration is done using **digital accumulators (summing registers)**.
- The combination of **three gyroscopes** and **three accelerometers** allows full **3D motion tracking** (yaw, pitch, roll).

Example: MPU6050 Sensor Module

- **6-axis motion tracking device**:
  - 3-axis accelerometer
  - 3-axis gyroscope
  - Digital Motion Processor (DMP)
- Additional features:
  - On-chip **temperature sensor**
  - **I^2C interface** for microcontroller communication
  - **Auxiliary I^2C** port for other sensors (e.g., 3-axis magnetometer, pressure sensor)
- When connected to a magnetometer, it can provide **9-axis motion fusion output**.

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5. Inclinometers (Tilt Sensors)

- Measure **absolute orientation angle** within a defined range.
- Output can be **analog voltage** or **PWM signal**.

Pros and Cons

- **Pros:**
  - Measure absolute angle (not rate), making them accurate for static orientation.
- **Cons:**
  - **Lag and oscillation** in presence of vibration or noise (e.g., servo jitter).
  - **Slower response**, making them unsuitable for fast control systems like balancing robots.

> [!TIP] Combine **inclinometer** (for steady-state accuracy) and **gyroscope** (for fast response) to achieve optimal orientation tracking.

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6. Digital Cameras in Robotics

- Among the **most complex sensors** used in robotics.
- Historically avoided in embedded systems due to high **processing** and **memory** demands.

Key Considerations

- **High frame rate** is crucial for mobile robots to capture rapidly changing environments.
- **Resolution** is less critical — even **60×80 pixels** can be sufficient for:
  - Object detection
  - Color-based tracking
  - Obstacle detection (e.g., robot soccer)

  > *Even low-resolution images (60×80) can effectively detect objects or obstacles for small robots.*

Summary

Sensor Type	Measures	Example Models	Notes
Sonar	Distance via sound	HC-SR04	Inexpensive but less precise
IR	Distance via reflection	Sharp GP2D02 / GP2D12	Sensitive to surface color and angle
Compass	Orientation (absolute)	HMC5883L	Good for navigation
Accelerometer	Linear acceleration	ADXL202	Used for motion sensing
Gyroscope	Angular velocity	GY130, MPU6050	Needed for orientation tracking
Inclinometer	Tilt angle (absolute)	Seika N3	Slow response
Camera	Visual data	USB / CMOS module	Used for vision-based robotics