Lab 02: Probability, Statistics & Matplotlib

1. Matplotlib Library

Matplotlib is a **Python library for data visualization**

It's mainly used to **create plots and graphs** so you can *see* your data instead of just printing numbers.

In simple words

Matplotlib helps you turn data into:

- line plots
- bar charts
- scatter plots
- histograms
- pie charts
- and more

It's super popular in **data science, engineering, machine learning, and research**.

1.1 Why people use Matplotlib

- Easy to use
- Works perfectly with **NumPy** and **Pandas**
- Highly customizable (colors, labels, titles, styles)

1.2 Where Matplotlib is used

- 📈 Data analysis
- Machine learning (visualizing results)
- ⚙ Engineering experiments
- 🎓 Academic research

1.3 Example

```python
import matplotlib.pyplot as plt

x = [1, 2, 3, 4]
y = [1, 4, 9, 16]

plt.plot(x, y)
plt.xlabel("X values")
plt.ylabel("Y values")
plt.title("Simple Line Plot")
plt.show()
```

2. Probability & Statistics

A. Expectation (Mean)

- Average value you expect in the long run
- Discrete: $E[X] = \sum x \cdot P(X = x)$
- Continuous: $E[X] = \int_{\infty}^{\infty} x f(x) dx$

B. Variance

- Measures spread around the mean
- Formula: $Var(X) = E[(X - E[X])^2]$

```python
import numpy as np

# Discrete: number of heads in 3 coin tosses
X = np.array([0,1,2,3])
P = np.array([1,3,3,1])/8  # PMF

# Expected value
E_X = np.sum(X * P)
Var_X = np.sum((X - E_X)**2 * P)

print("E[X] =", E_X)   # 1.5
print("Var[X] =", Var_X) # 1.125
```

```python
# Continuous: Normal random variable
import matplotlib.pyplot as plt
from scipy.stats import norm

x = np.linspace(140, 200, 500)
f = norm.pdf(x, loc=170, scale=10)

plt.plot(x, f)
plt.title("Normal PDF: μ=170, σ=10")
plt.show()
```

3. EXERCISE – Matplotlib for Engineering Applications

🎯 Objective

Learn how to:

- Create **multiple plot types**
- **Customize** plots
- **Organize figures** using subplots

Applications:

- Electrical Engineering
- Electromechanical Systems
- Renewable Energy

📝 GIVEN DATA

1️⃣ Electrical Engineering – AC Current

Time vector:

```python
t = np.linspace(0, 0.1, 1000)
```

Current:

$$i(t) = 10\sin(2\pi 50t)$$

2️⃣ Electromechanical – DC Motor

Speed (rpm):

```python
speed = [0, 500, 1000, 1500, 2000]
```

Torque (Nm):

```python
torque = [60, 55, 45, 30, 10]
```

3 Renewable Energy – Solar Power

Hours of the day:

```python
time_day = np.linspace(0, 24, 24)
```

Solar irradiance (W/m^2):

```python
irradiance = [0,0,0,0,50,200,400,600,750,800,820,830,
              820,800,750,600,400,200,50,0,0,0,0,0]
```

Panel efficiency = **18%**

Q 1

Plot the **AC current vs time** using a **line plot.**

Add:

- Title
- Axis labels
- Grid

Q 2

Plot the **Torque-Speed characteristic** of the DC motor using a **scatter plot.**

Customize:

- Marker size
- Marker shape

Q3

Plot the **solar power output** using a **bar chart**.

$$P = \eta \times \text{Irradiance}$$

Q4

Organize the **three plots in one figure** using **subplots (3 rows, 1 column)**.

Q5

Save the final figure as **engineering_plots.png** with high quality.

4. Homework

4.1 Data Visualization with Matplotlib

🎯 Objective

Learn how to create **multiple types of plots**, customize them, and organize figures using **Matplotlib**.

Exercise Statement

You are given data representing the **monthly sales of a company** during one year.

```
months = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun',
          'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']
sales_2024 = [120, 135, 150, 145, 160, 170,
              180, 175, 165, 190, 200, 210]
expenses_2024 = [80, 90, 95, 100, 110, 120,
                 125, 130, 120, 135, 140, 150]
```

Part 1: Line Plot

1. Plot **sales** vs months
2. Plot **expenses** vs months on the same graph
3. Add:
    - Title
    - X & Y labels
    - Legend
    - Grid

Part 2: Bar Chart

4. Create a **bar chart** for monthly sales
5. Change bar width
6. Rotate x-axis labels

Part 3: Scatter Plot

7. Create a scatter plot:
    - X → expenses
    - Y → sales
8. Add title and axis labels

Part 4: Subplots

9. Create **2 subplots**:
    - First: line plot (sales & expenses)
    - Second: bar chart (sales only)

Part 5: Save the Figure

10. Save the figure as `company_report.png`

4.2 Homework Exercise: DC Motor with Matplotlib

Problem Statement

A **DC motor** is modeled by the following equations:

3. 1 Electrical equation

$$V(t) = Ri(t) + L\frac{di(t)}{dt} + e(t)$$

with back-EMF:

$$e(t) = K_e\,\omega(t)$$

3. 2 Mechanical equation

$$J\frac{d\omega(t)}{dt} + B\omega(t) = K_t\,i(t)$$

Given Parameters

Parameter	Value
Supply voltage V	24 V
Resistance R	2 Ω
Inductance L	0.5 H
Torque constant K_t	0.1 Nm/A
Back-EMF constant K_e	0.1 V·s/rad
Inertia J	0.02 kg·m²
Friction B	0.02 N·m·s
Load torque	0

Tasks

1. Simulate the **current i(t)** and **angular speed ω(t)** for **0–5 seconds**
2. Plot:
    - Current vs time
    - Angular speed vs time
3. Interpret the results physically