Ex. No. : 3 Date:	**Smart Manufacturing Sensor Relationship Analysis**

PROBLEM STATEMENT:

A smart manufacturing unit collects sensor data including temperature, pressure, vibration level, and energy consumption from industrial machines. Engineers want to analyze how sensor readings are interrelated to monitor machine health. Perform covariance and correlation analysis, construct the covariance matrix, and interpret relationships among sensor variables to identify early warning indicators of machine failure.

Aim

To analyze smart manufacturing sensor data using covariance and correlation analysis in order to understand relationships among sensor variables and identify early warning indicators of machine failure.

Introduction

In a smart manufacturing system, industrial machines are equipped with multiple sensors to continuously monitor machine conditions. Common sensors include temperature, pressure, vibration level, and energy consumption.

These sensor readings are not independent. For example, increased temperature may lead to higher energy consumption or abnormal vibration. Analyzing the relationships between sensor variables helps engineers detect faults early and perform predictive maintenance, thereby reducing downtime and repair costs.

Problem Definition

A manufacturing unit collects sensor data from machines, including:

- Temperature
- Pressure
- Vibration level
- Energy consumption

The objective is to:

- Analyze how sensor readings are interrelated
- Construct a covariance matrix
- Perform correlation analysis
- Identify early warning signs of machine failure

DESIGN DOCUMENT

Methodology

The following steps are followed:

- Represent sensor data using vectors and matrices
- Compute mean and variance for each sensor variable
- Construct the covariance matrix
- Compute the correlation matrix
- Interpret relationships among sensor variables
- Identify early indicators of machine malfunction

Dataset Description

Variable	Description
Temperature (°C)	Operating temperature of the machine
Pressure (bar)	Internal operating pressure
Vibration Level (mm/s)	Mechanical vibration intensity
Energy Consumption (kWh)	Power consumed by the machine

Data Representation (Linear Algebra)

The sensor dataset is represented as a matrix, where rows correspond to observations and columns represent sensor variables:

$$X = \begin{bmatrix} T_1 & P_1 & V_1 & E_1 \\ T_2 & P_2 & V_2 & E_2 \\ \vdots & \vdots & \vdots & \vdots \\ T_n & P_n & V_n & E_n \end{bmatrix}$$

Mathematical Model

- **Mean**:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i$$

- **Variance**:

$$\sigma^2 = \frac{1}{n-1}\sum(x_i - \mu)^2$$

- **Covariance**:

$$\text{Cov}(X,Y) = \frac{1}{n-1}\sum(X_i - \bar{X})(Y_i - \bar{Y})$$

- **Correlation**:

$$r = \frac{\text{Cov}(X,Y)}{\sigma_X \sigma_Y}$$

Tools / Software Required

- Python 3.x
- Jupyter Notebook
- NumPy
- Pandas
- Seaborn
- Matplotlib

Step 1: Sample Dataset

Temperature (°C)	Pressure (bar)	Vibration (mm/s)	Energy (kWh)
60	115	2.1	16
65	118	2.4	17
70	122	2.8	19
75	128	3.2	21
80	135	3.7	24

Step 2: Import Libraries

```
import numpy as np

import pandas as pd

import seaborn as sns

import matplotlib.pyplot as plt
```

Step 3: Load Data

```
# Step 2: Load the CSV dataset

data = pd.read_csv("sensor_data.csv")
```

print("Dataset:")

print(data)

Step 4: Descriptive Statistics

mean_values = data.mean()

variance_values = data.var()

mean_values

variance_values

Step 5: Covariance Matrix

cov_matrix = data.cov()

cov_matrix

Interpretation

- Positive covariance → sensor values increase together
- Negative covariance → inverse relationship

Step 6: Correlation Matrix

corr_matrix = data.corr()

corr_matrix

Correlation values range between –1 and +1.

Step 7: Visualization

sns.heatmap(corr_matrix, annot=True, cmap="coolwarm")

plt.title("Correlation Matrix – Smart Manufacturing Sensors")

plt.show()

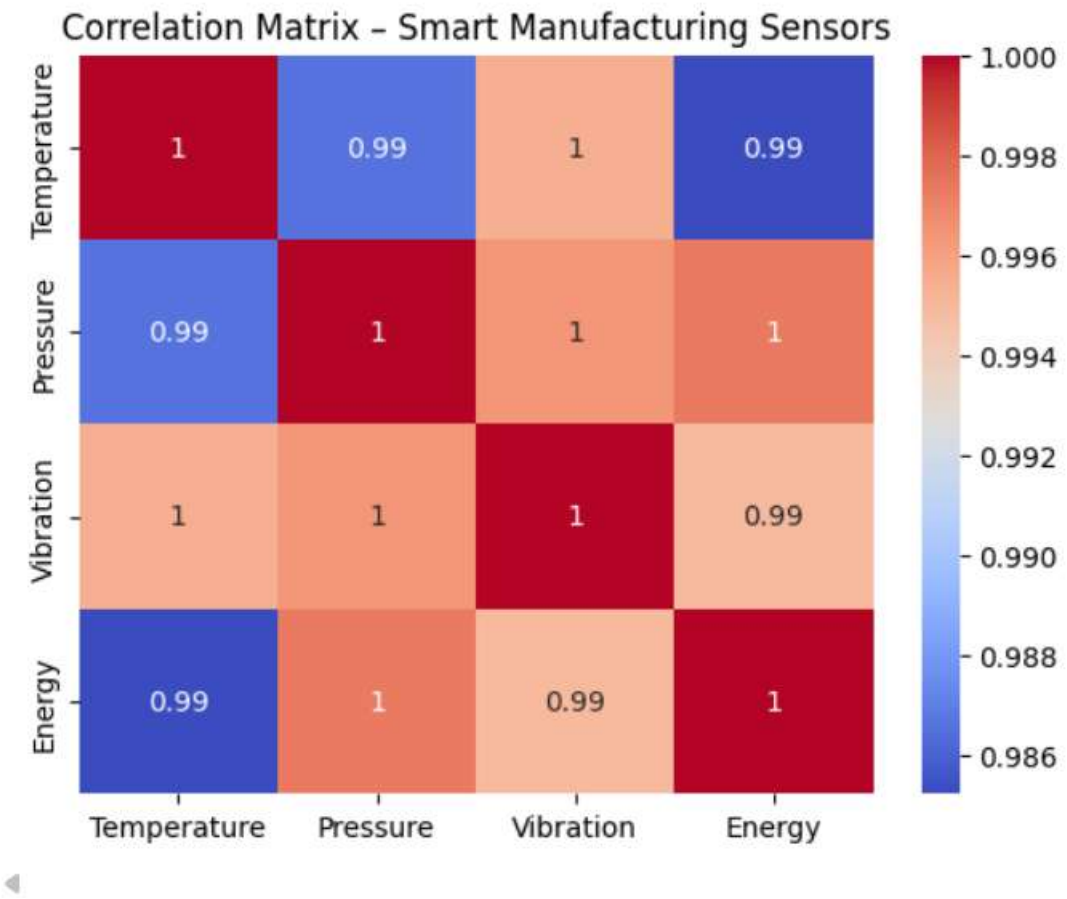
Step 8: Interpretation

- Strong positive correlation between temperature and energy consumption
- Vibration positively correlates with temperature and pressure
- Energy consumption correlates with all sensors, indicating machine load
- Pressure shows moderate correlation with vibration, indicating mechanical stress

Inference (Optional)

- Rising temperature and vibration indicate mechanical wear
- Increased energy consumption signals inefficiency or overheating
- Pressure–vibration dependency highlights stress-related faults
- Covariance and correlation analysis help detect early warning indicators of machine failure

OUTPUT:


Correlation Matrix – Smart Manufacturing Sensors
Temperature
Pressure
Vibration
Energy
1
0.99
1
0.99
0.99
1
1
1
1
1
1
0.99
0.99
1
0.99
1
1.000
0.998
0.996
0.994
0.992
0.990
0.988
0.986
Temperature
Pressure
Vibration
Energy

RUBRICS:

PROBLEM UNDERSTANDING AND OBJECTIVE CLARITY (10)	DESIGN DOCUMENT (10)	IMPLEMENTATION (15)	OUTPUT (5)	TIME MANAGEMENT (5)	VIVA (5)	TOTAL (50)

RESULT:

Thus, smart manufacturing sensor data was analyzed using descriptive statistics, covariance, and correlation anal ysis to identify relationships among sensor variables and detect early signs of machine malfunction.