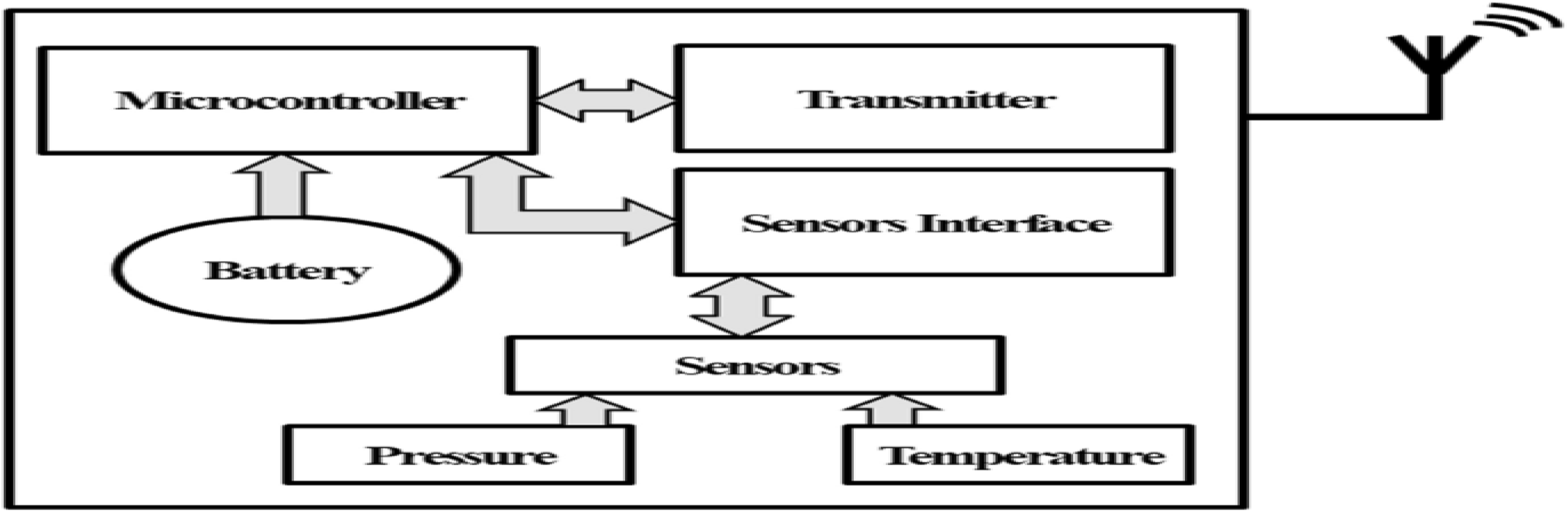
Intelligent Tire Pressure Monitoring System (TPMS)

This system is designed to monitor tire pressure in real-time, providing alerts and automated adjustments to maintain optimal pressure. It integrates **IoT, sensors, cloud storage, and AI-based predictive analytics** to enhance safety, fuel efficiency, and tire lifespan.



System Architecture

The system consists of the following key components:

1. **Pressure Sensors (MEMS-based or Piezoelectric Sensors)** – Measure real-time tire pressure.
2. **Temperature Sensors** – Monitor tire temperature variations that affect pressure.
3. **ESP32/ESP8266 (IoT Controller)** – Sends sensor data to a cloud server and mobile app.
4. **Blynk/Thing Speak Cloud** – Stores and visualizes data for remote monitoring.
5. **AI/ML Model (Optional)** – Predicts tire issues based on historical pressure trends.
6. **OLED/LED Display** – Shows real-time tire pressure.
7. **Relay-Driven Air Compressor (Optional)** – Automatically inflates or deflates tires.
8. **Mobile App & Web Dashboard** – Provides alerts, logs data, and suggests maintenance.

Working Principle

- **Real-time Data Acquisition:**
- Sensors measure tire pressure & temperature and send the data to the ESP32/ESP8266 module.
- **Data Processing & Transmission:**
- The ESP32 sends processed data to the cloud via WiFi /Bluetooth.
- **User Alert System:**
- If the pressure is too low or too high, a buzzer or app notification alerts the driver.
- **Predictive Analytics:**
- AI models analyze past trends to predict slow leaks or potential failures.
- **Automatic Tire Inflation/Deflation:**
- A relay module controls an air pump to maintain optimal pressure when needed.

Advantages

✅ Real-time monitoring & remote access.
✅ Enhances safety by preventing tire bursts.
✅ Improves fuel efficiency.
✅ AI-based predictions reduce maintenance costs.

Sensors

Sensors are devices that detect changes in physical, chemical, or biological conditions and convert them into electrical signals for monitoring and automation. They are widely used in **IoT, robotics, automation, healthcare, automotive, and industrial applications**.

Different Types of Sensors

Classification of Sensors

Sensors can be categorized based on their **working principle, measured parameter, and application**:

A. Based on Measured Parameter

Sensor Type	Measured Parameter	Examples
Temperature Sensors	Heat/Cold levels	LM35, DHT11, Thermocouple
Pressure Sensors	Force exerted by a fluid/gas	Piezoelectric, MEMS, BMP180
Humidity Sensors	Moisture in the air	DHT22, HIH-4000
Proximity Sensors	Object detection	IR, Ultrasonic, Capacitive
Gas Sensors	Air composition	MQ-2, MQ-135, CO2 Sensors
Optical Sensors	Light intensity	LDR, Photodiodes
Motion Sensors	Movement detection	PIR, Accelerometer
Touch Sensors	Physical contact	Capacitive touch modules
Current/Voltage Sensors	Electrical parameters	ACS712, INA219
Vibration Sensors	Mechanical oscillations	Piezoelectric vibration sensors
pH Sensors	Acidity/alkalinity	Glass electrode pH sensor

B. Based on Working Principle

1. **Resistive Sensors**
   1. Detect changes in resistance when exposed to external conditions.
   2. Example: LDR (Light Dependent Resistor), Thermistor.
2. **Capacitive Sensors**
   1. Measure changes in capacitance due to nearby objects or environmental factors.
   2. Example: Capacitive Touch Sensors, Proximity Sensors.
3. **Inductive Sensors**
   1. Work based on electromagnetic induction to detect metallic objects.
   2. Example: Inductive Proximity Sensors.
4. **Piezoelectric Sensors**
   1. Convert mechanical pressure or vibrations into electrical signals.
   2. Example: Piezoelectric Pressure Sensors, Vibration Sensors.
5. **Optical Sensors**
   1. Use light signals (LED, laser) to detect objects or measure intensity.
   2. Example: IR Sensors, Photodiodes.
6. **MEMS (Micro-Electromechanical Systems) Sensors**
   1. Small, integrated sensors that detect motion, acceleration, and pressure.
   2. Example: MPU6050 (Accelerometer & Gyroscope), BMP280 (Pressure Sensor).

C. Based on Application

1. **Automotive Sensors** – Speed Sensors, Tire Pressure Sensors, Oxygen Sensors.
2. **Industrial Sensors** – Gas Sensors, Proximity Sensors, Vibration Sensors.
3. **Medical Sensors** – ECG, Glucose Sensors, Pulse Oximeters.
4. **Environmental Sensors** – Air Quality, Humidity, Temperature Sensors.

Actuators

An actuator is a device that converts electrical, hydraulic, or pneumatic energy into mechanical motion. It is used in **automation, robotics, IoT, automotive systems, and industrial machinery** to control movement, positioning, or force application.

1. Classification of Actuators

Actuators can be categorized based on their **working principle, motion type, and application**.

A. Based on Energy Source

Actuator Type	Energy Source	Examples
Electric Actuators	Electrical energy	Servo motors, Stepper motors, Solenoids
Pneumatic Actuators	Compressed air	Air cylinders, Pneumatic valves
Hydraulic Actuators	Hydraulic fluid pressure	Hydraulic pistons, Hydraulic motors
Thermal Actuators	Heat energy	Shape memory alloys (SMA), Thermostatic valves
Magnetic Actuators	Magnetic fields	Magnetic relays, Electromagnetic coils

B. Based on Motion Type

1.Linear Actuators

1. Convert energy into straight-line motion.
2. Example: Lead screw actuators, Pneumatic cylinders.

2.Rotary Actuators

1. Convert energy into rotational movement.
2. Example: Servo motors, Stepper motors.

C. Based on Working Mechanism

1. Electric Actuators

- Use electric current to generate motion.
- **Examples:**
    - **Solenoids** (Electromagnetic coil-based actuators) – Used in door locks, relays.
    - **Servo Motors** (Closed-loop control, precise positioning) – Used in robotics, automation.
    - **Stepper Motors** (Discrete step rotation) – Used in 3D printers, CNC machines.

2. Pneumatic Actuators

- Operate using **compressed air** for fast and precise movements.
- **Examples:**
    - Pneumatic Cylinders – Used in industrial automation.
    - Pneumatic Valves – Used in fluid control systems.

3. Hydraulic Actuators

- Use **hydraulic fluid pressure** to generate strong motion.
- **Examples:**
    - Hydraulic Pistons – Used in heavy machinery, car brakes.
    - Hydraulic Motors – Used in cranes, excavators.

4. Thermal Actuators

- Expand or contract based on temperature changes.
- **Examples:**
    - Shape Memory Alloy (SMA) Actuators – Used in medical devices.
    - Thermostatic Valves – Used in temperature control systems.

5. Magnetic Actuators

- Use magnetic fields to produce motion.
- **Examples:**
    - Electromagnetic Relays – Used in switching circuits.
    - Magnetic Levitation Systems – Used in maglev trains.

3. Applications of Actuators

Industry	**Common Applications**
IoT & Home Automation	Smart locks, Smart HVAC systems
Automotive	Electric power steering, Brake actuators
Robotics	Robot arms, Humanoid movement
Medical Devices	Prosthetic limbs, Medical pumps
Industrial Automation	CNC machines, Conveyor belts

Communication Protocols Used in Smart Sensor Systems

1. I²C (Inter-Integrated Circuit) Protocol

Features:

✅ **Multi-Master, Multi-Slave Communication** – Multiple devices can communicate on the same bus.
✅ **Uses Two Wires** – SDA (Data) and SCL (Clock).
✅ **Low Power Consumption** – Suitable for embedded and battery-powered devices.
✅ **Supports Multiple Devices** – Each device has a unique address.
✅ **Common in IoT & Sensor Networks** – Used in temperature sensors, accelerometers, and LCD modules.

Use Case:

✔ Used in Arduino and Raspberry Pi projects for sensor interfacing.

2. SPI (Serial Peripheral Interface) Protocol

Features:

✅ **High-Speed Communication** – Faster than I²C, supports clock speeds up to several MHz.
✅ **Full-Duplex Mode** – Can send and receive data simultaneously.
✅ **Four-Wire Interface** – MOSI (Master Out, Slave In), MISO (Master In, Slave Out), SCLK (Clock), SS (Slave Sele
✅ **Used for Short-Distance Communication** – Between microcontrollers, sensors, and memory modules.
✅ **Efficient for High-Speed Data Transfer** – Used in ADCs, LCD displays, and SD card modules.

Use Case:

✔ Common in **real-time sensor applications like gyroscopes and high-speed ADCs**.

3. UART (Universal Asynchronous Receiver-Transmitter) Protocol

Features:

✅ **Asynchronous Communication** – No clock signal needed; uses start and stop bits for synchronization.
✅ **Simple Two-Wire Interface** – TX (Transmit) and RX (Receive).
✅ **Flexible Baud Rate** – Speeds range from 9600 bps to several Mbps.
✅ **Widely Used in IoT and Embedded Systems** – ESP8266, GSM modules, and GPS modules use UART.
✅ **Error Detection Mechanism** – Includes parity and stop bits for error checking.

Use Case:

✓ Used in **ESP8266 (WiFi module)** and **GPS receivers** for serial communication.

4. MQTT (Message Queuing Telemetry Transport) Protocol

Features:

✅ **Lightweight IoT Protocol** – Designed for low-bandwidth, high-latency networks.
✅ **Uses Publish-Subscribe Model** – Sensors publish data to a broker, and subscribers receive updates.
✅ **Low Power Consumption** – Ideal for battery-powered IoT devices.
✅ **Reliable Data Transmission** – Supports QoS levels for message delivery.
✅ **Works on TCP/IP** – Used in cloud-based IoT applications.

Use Case:

✓ Used in **Blynk IoT platforms** for sending sensor data to cloud servers.

5. Zigbee Protocol

Features:

✅ **Low-Power, Wireless Mesh Network** – Ideal for IoT and smart home applications.
✅ **Operates on 2.4 GHz Frequency** – Supports short-range communication (10–100 meters).
✅ **Self-Healing Network** – Devices can reroute data if a node fails.
✅ **Supports Thousands of Nodes** – Scalable for industrial applications.
✅ **Secure Communication** – Uses AES encryption for data security.

Use Case:

✓ Used in **smart home automation**, **industrial IoT sensors**, and **Zigbee-based smart meters**.

Conclusion

Each protocol has unique advantages based on speed, power consumption, and communication range.

Protocol	**Best For**
I²C	Low-speed, multiple sensors on a shared bus.
SPI	High-speed, real-time data transfer.
UART	Simple serial communication for IoT modules.
MQTT	Cloud-based IoT sensor data transmission.
Zigbee	Wireless, low-power smart home networks.