

Advanced Air Quality Monitoring Techniques

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Key concepts, technologies, and practical considerations for modern air pollution surveillance.

1. Why Move Beyond Traditional Monitoring?

Limitation of Conventional Methods	Advanced Approach Benefits
Sparse network – few fixed stations ? poor spatial resolution	High-density sensing – mobile, distributed, or satellite platforms fill gaps
Delayed results – sample collection ? lab analysis	Near-real-time data – on-site analysis, rapid alerts
Limited pollutant suite – typically PM _{2.5} , PM ₁₀ , NO ₂ , O ₃ , CO, SO ₂	Broad speciation – VOCs, ultrafine particles, black carbon, pollen, microbial aerosols
High operational cost – maintenance, calibration	Lower cost per unit – MEMS, low-power sensors enable large deployments
Poor source attribution	Integrated data streams (meteorology, traffic, GIS) support source-receptor modeling

2. Core Technologies

2.1. Low-Cost Sensor (LCS) Networks

- **Principle:** Electrochemical, metal-oxide semiconductor (MOS), or optical scattering sensors miniaturized on printed circuit boards.
- **Typical pollutants:** CO, NO₂, O₃, SO₂, PM_{2.5}/PM₁₀.
- **Key features**
 - **Power:** <1W, often solar- or battery-powered.
 - **Communications:** LoRaWAN, NB-IoT, Wi-Fi, cellular.
 - **Calibration:** Laboratory co-location, field machine-learning drift correction.

2.2. Photonic & Spectroscopic Instruments

Technique	Detects	Strengths	Typical Deployments
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Cavity Ring-Down Spectroscopy (CRDS)	CO ₂ , CH ₄ , N ₂ O, H ₂ O	Sub-ppb precision, fast response	Stationary towers, aircraft
Fourier-Transform Infrared (FTIR) Spectroscopy	Multi-gas (VOC, CO, NO _x , SO ₂)	Full speciation, path-averaged	Urban monitoring stations, plume studies
Tunable Diode Laser Absorption Spectroscopy (TDLAS)	NO, NO ₂ , NH ₃ , H ₂ S	High selectivity, low interference	Industrial stacks, roadside monitors
Raman Lidar	Aerosol extinction, water vapor	3-D vertical profiling, long range	Research aircraft, ground-based remote sensing

2.3. Particle-Based Advanced Instruments

- **Scanning Mobility Particle Sizer (SMPS)** – size distribution of particles 10 nm–1 µm.
- **Aerosol Mass Spectrometer (AMS)** – real-time chemical composition (organics, nitrate, sulfate, ammonium, BC).
- **Single-Particle Laser-Induced Fluorescence (SP-LIF)** – bioaerosol detection, pollen identification.

2.4. Satellite Remote Sensing

Sensor	Spectral Range	Main Products	Spatial/Temporal Resolution
MODIS (Aqua/Terra)	Visible-IR	AOD, fire hotspots	10 km, daily
Sentinel-5P TROPOMI	UV-Vis-IR	NO ₂ , SO ₂ , CO, CH ₄ , O ₃	