Supplementary Materials

1. Sensor Design and Fabrication Strategies

Table S1. Advantages, limitations, cost, applications and detection & response ranges for different synthesis procedures on paper.

Synthesis Procedure	Advantages	Limitations	Scalability	Cost	Application	Detection Range	Response Time	Reference
Solution-coating of Co_3O_4 and Fe_2O_3 on paper	Selective, eco-friendly, disposable	Moderate sensitivity	High	Low	Air quality monitoring	0.25–2500 ppm	Not specified	[1]
Aerosol jet printing of PEDOT:PSS + flash lamp annealing	Fast, scalable, selective	Humidity interference	Very High	Moderate	Food spoilage monitoring	3–12 ppm	< 10 s	[2]
Drop-casting ZnTPP on CNT paper, hot-pressed	Room-temp operation, stable	Slow recovery (531 s)	Medium	Moderate	Industrial NH_3 detection	Not specified (used 200 ppm)	162 s (response), 531 s (recovery)	[3]
Immersion of paper in mango leaf extract	Natural, non-toxic, smartphone-readable	Moderate reproducibility	Low–Medium	Very Low	Aquaculture wastewater	1.7–10 mg/L	10 min	[4]
Decoration with PPy/CNT/Pt nanocomposites	Twistable, washable, ultra-sensitive	Complex synthesis	Medium	Moderate	Wearable sensors, diagnostics	5 ppb–60 vol%	Not specified	[5]
In-situ polymerization of aniline on paper	Cost-effective, fast, flexible	Slight drift over time	High	Low	Environmental & industrial use	12–1000 ppm	9–30 s	[6]
Drop-casting $CH_3NH_3PbX_3$ on paper	Dual-mode (color/electrical), low power	Degradation over time	High	Low	Breath analysis, pollution	Visual: ~10 ppm, Electrical: sub-ppm	Fast (not quantified)	[7]
Paper discs + bromothymol blue, 3D-printed reader	Portable, high precision, reusable	Calibration needed	Medium–High	Moderate	Wastewater & digesters	5–50 mg/L	~10 min	[8]

2. Applications and Implementation in the Real World

Table S2. Cost and accessibility.

Method	Cost Per Test	Equipment Requirements
Paper-based colorimetric	<$0.10–0.50	None; optional smartphone
Paper-based chemiresistive	~$0.50–1.00	Low-power handheld reader
Nessler’s reagent	~$1.00–2.00	Spectrophotometer and reagents
Ion-selective electrodes	~$2.00–5.00 (after capital cost)	pH/ISE meter; calibration solutions
Electrochemical gas sensors	~$150–300 per device	Continuous monitoring instruments

Table S3. Portability and field usability.

Method	Portability	Field Suitability	Notes
Paper-based	Ultra-light, disposable, portable	Excellent	Compatible with smartphone readout; ideal for point-of-need
Nessler's reagent	Poor	Limited	Requires reagents, glassware, and waste disposal
Ion-selective electrodes	Moderate	Good	Requires calibration and maintenance; battery-powered
Electrochemical gas sensors	Good	Excellent	Rugged, continuous monitoring; higher cost

Table S4. Response and recovery time.

Method	Response/Recovery Time	Notes
Paper-based colorimetric	Visual response within ~1–3 min; slower recovery	Passive diffusion limits dynamics
Paper-based chemiresistive (CNT, WS_2-PANI)	9–60 s response; 30–120 s recovery	Rapid surface adsorption/desorption; good repeatability
Nessler wet chemistry	~10–15 min including reagent mixing	Requires laboratory setup
Ion-selective electrodes	<1 minute response; stable continuous readout	Requires calibration and sample prep
Electrochemical gas sensors	~10–60 s response and recovery	Active sensing; continuous

Table S5. Detection sensitivity and dynamic range.

Method	LOD/Sensitivity	Dynamic Range	Reference
Paper-based (colorimetric, anthocyanin/mango extract)	~0.50–2.00 mg L^{-1} (aqueous); ~3–12 ppm (gas)	Aqueous: 1.7–10 mg L^{-1}; Gas: up to 500 ppm	[4,9]
Paper-based (nanocomposites–WS_2-PANI, MXene, CNT hybrids)	~5 ppb to ~3 ppm	Gas: 5 ppb to 60% v/v	[5,10,11]
Nessler's reagent (wet chemistry)	~0.01 mg L^{-1} (10 ppb)	Up to ~10 mg L^{-1} (aqueous)	Standard APHA protocols
Ion-selective electrodes (ISE)	~0.05 mg L^{-1} (50 ppb)	0.05–100 mg L^{-1} (aqueous)	Commercial NH_3 ISE datasheets
Electrochemical gas sensors (industrial)	~1 ppm	0–1000 ppm	Industrial gas detectors (Honeywell, Figaro, Dräger)

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