Localized and Distributed Information in Dust Collection Systems
A New Capillary Monitoring Architecture for the Cement Industry

CleanAir Europe – Technical Article (2025) by Corrado Maggi
Based on AICCE28 Conference Presentation

1. Introduction

Industrial dust collection in cement production has evolved from a compliance-driven function to a strategic component of plant reliability, environmental performance, and operational safety. In the context of rising ESG requirements, energy efficiency goals, and the transition toward digitally integrated industrial systems, dust collectors are expected to deliver higher performance with lower operating costs.

CleanAir Europe's research program—inaugurated at AICCE27 (Tunis, 2024)—introduced a disruptive concept: **capillary-level monitoring inside filter bags and cages**, enabling true localized and distributed information within the dust collector. This architecture aims to bridge the gap between theoretical innovation and measurable field impact.

At AICCE28 (Dubai, 2025), the company presented a complete technology framework demonstrating how embedded sensors, energy-harvesting electronics, AI-driven data fusion, and digital twin methodologies can reshape filtration management.

2. Digitalization: From Data Collection to Decision Intelligence

Until recently, dust collectors generated minimal diagnostic information—primarily differential pressure, fan behavior, and occasional emissions data. Modern plants require more.

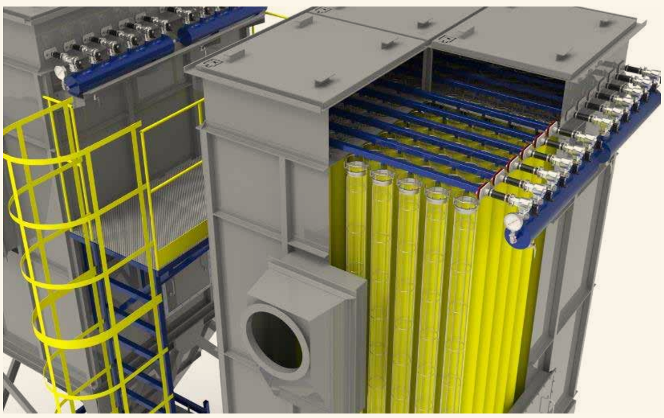
CleanAir Europe's approach introduces **connected multi-sensor nodes embedded directly in filter cages and bags**, transforming each filter element into a data point. These sensors might monitor:

- temperature
- local pressure variations
- humidity
- vibration
- particle concentration
- airflow patterns at bag level

Data is transmitted wirelessly via low-energy protocols, enabling real-time monitoring without intrusive cabling.

Predictive maintenance becomes achievable through continuous tracking of filter clogging, cleaning efficiency, fan imbalance, and localized temperature anomalies. AR (Augmented Reality) and NFC support tools simplify service routines by giving operators instant access to sensor history and diagnostic alerts.

The dust collector becomes an **active cyber-physical component**, no longer a passive endpoint.



3. Sustainability: Efficiency by Engineering Design

Energy consumption remains one of the highest operating costs in filtration systems. CleanAir Europe highlights several design elements impacting sustainability:

- **CFD-optimized housings and components** to reduce pressure losses
- **High-efficiency fans** minimizing electrical demand
- **Advanced filter media** capable of achieving **PM emissions below 1 µg/m³**
- System-level eco-design aimed at reducing the mechanical load during cleaning cycles

By integrating distributed data directly from inside the filter pack, operators can optimize airflows, detect inefficient cleaning sequences, and calibrate pulse-jet pressures, ultimately lowering energy use.

The sustainability model also supports unified dashboards aligned with **ISO 50001** and **ESG reporting**, allowing plants to track their real-time carbon and energy indicators.

4. Safety: Data-Driven Prevention of Dust Hazards

Combustible dust risks remain critical in cement and mineral handling. CleanAir's system adheres to ATEX and OSHA standards while enabling predictive hazard identification:

- Temperature sensors detect **ignition precursors**
- Particle sensors identify **filter bag leaks** and early emissions spikes
- Differential pressure analytics detect **fan anomalies** and opportunities for energy optimization
- AI-based triggers enable **automated isolation** or alarm activation

By embedding sensor intelligence throughout the filter array, operators gain continuous verification of safe operating conditions, significantly reducing the likelihood of catastrophic events.

5. A New Monitoring Architecture: Capillary and Distributed

The core innovation lies in the **capillary monitoring concept:**

Smart Multi-Sensor Nodes

Installed inside cages and integrated into filter fabrics, they operate as a distributed array capturing hyper-local information.

Energy-Harvesting Operation

Low-power electronics harvest energy from airflow, vibration, or thermal gradients, extending lifespan and reducing maintenance overhead.

Standard Protocol Integration

Compatible with DCS/PLC and modern digital environments via OPC-UA, MQTT, and other industrial protocols.

Plug-and-Play Deployment

Compact, non-intrusive modules suited both for new installations and retrofit projects—addressing the sector's pressing need for simplicity and cost-effectiveness.

This architecture enables **"information at the fingertip"**: high-resolution process visibility without operator burden.

6. AI Data Fusion and Cloud-Based Analytics

The system could include a multi-layer data interpretation model:

- **Base analytics** correlate raw variables (temperature, vibration, differential pressure)
- **AI-driven algorithms** identify emerging anomalies such as incipient clogging, fan imbalance, or irregular dust loading
- Cloud-based dashboards enable **predictive actions** and **process optimization**
- Continuous learning models refine operational recommendations over time

This combination allows plants to shift from reactive maintenance to **proactive and eventually autonomous filtration management.**

7. Digital Twin Integration

A full digital twin of the dust collector could be generated and included in the offer, incorporating:

- CFD simulations of airflow and particulate behavior
- Environmental scenario modeling
- Predictive lifecycle performance analysis

Real-world sensor feedback continuously updates the twin, ensuring accurate forecasting of filter aging, cleaning cycle optimization, and energy consumption trends.

This digital replica becomes a strategic tool for design validation, OPEX reduction, and maintenance planning.

8. Industry Challenges and Technological Barriers

Despite clear advantages, implementing distributed monitoring requires addressing several constraints:

- Harsh environmental conditions (abrasive dust, high temperatures)
- Extended electronic lifetime and thermal protection
- Minimal installation time and low operator overhead
- Maintenance requirements for probe cleaning
- Cost-sensitive markets demanding affordable large-scale deployment

CleanAir Europe's solution tackles these through robust mechanical design, optimized firmware, high-temperature electronics, and modular plug-and-play architecture.

9. Proof of Concept and Field Pilot Results

A full proof-of-concept was deployed on an industrial dust collector line, equipped with:

- Multi-sensor capillary units
- Cloud-based monitoring dashboard
- AI-assisted diagnostic layer

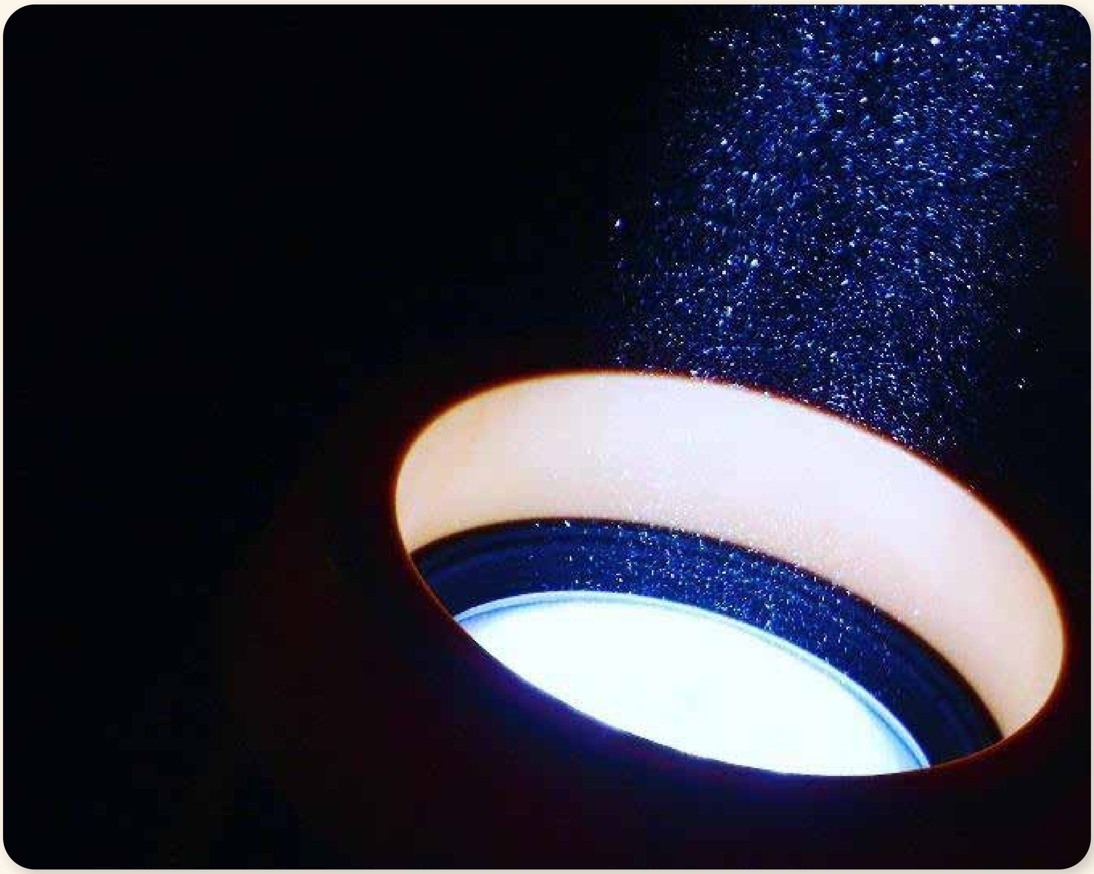
Key Performance Indicators (KPIs) monitored:

- energy use
- pressure drop patterns
- emissions and dust concentration
- thermal behavior inside the filter pack

Expected and preliminary results:

- >20% reduction in unplanned maintenance events
- 10–15% reduction in energy consumption
- improved emission stability
- optimized cleaning cycles and extended filter lifespan

Next steps involve full-scale deployment, AI-driven recommendations, and integration with plant ERP and DCS platforms.



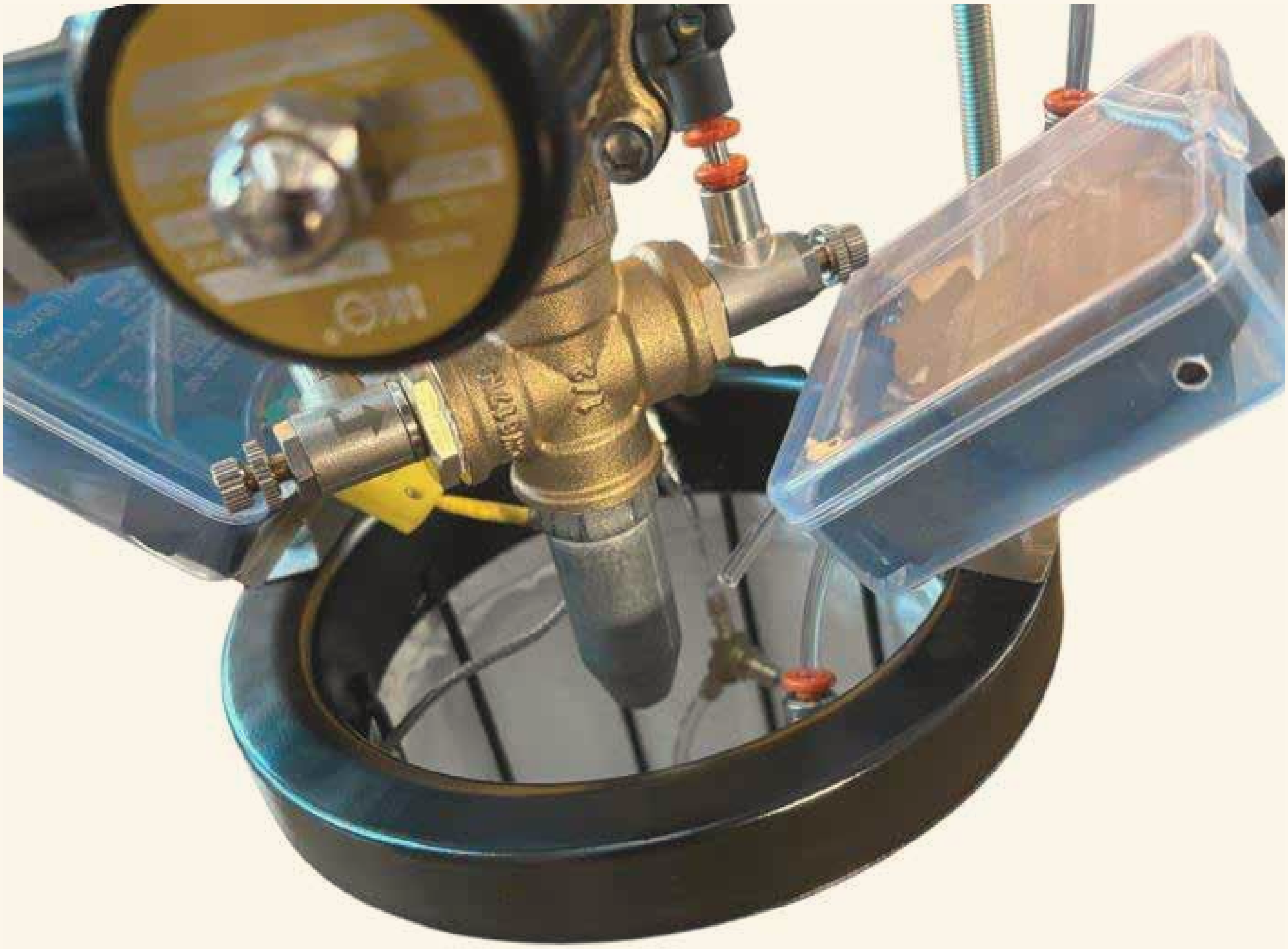
10. Conclusion

The transition toward **digitally intelligent, sustainable, and safety-centric dust collection** is accelerating across the cement industry. CleanAir Europe's capillary monitoring system EcoSense represents a fundamental shift in how filtration systems are designed, operated, and maintained.

By bringing data granularity down to the level of **individual filter bags and cages**, dust collectors become:

- more energy efficient
- safer
- more reliable
- fully integrated with plant digital ecosystems

This architecture positions the dust collector as a future-ready asset—one capable of meeting the strict environmental, operational, and safety demands defining the cement industry in 2025 and beyond.



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