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REVIEW ARTICLE

Portable Monitor with Smart Sensors for Volatile Compound Detection: Advances and Challenges in Monitoring Systems

Monitor portátil con sensores inteligentes para la detección de compuestos volátiles: avances y desafíos en los sistemas de monitoreo

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Abstract. The efficient monitoring of volatile organic compounds (VOCs) has become an essential priority in fields such as environmental protection, occupational health, and industrial safety due to their significant impact on air quality and human well-being. This article provides an in-depth review of recent advancements in portable monitoring systems that incorporate smart sensor technologies for VOC detection. Progress in sensor miniaturization, advanced signal-processing algorithms, and low-power electronic design has enabled the development of compact devices capable of real-time measurement with high levels of sensitivity and chemical selectivity. Furthermore, the integration of these systems into Internet of Things architectures has expanded their functionality, allowing for continuous data transmission, remote device management, and the application of predictive analytics through Big Data platforms. These capabilities not only enhance early detection of hazardous exposure but also support large-scale environmental surveillance and industrial process optimization. Despite these technological advances, several challenges persist. Issues related to long-term sensor calibration, environmental interferences, data reliability, and energy efficiency continue to limit widespread adoption. Additionally, ensuring interoperability among different communication protocols and maintaining cybersecurity standards remain critical considerations for future deployment. This review also outlines the growing range of applications for portable VOC monitors, including workplace exposure assessment, industrial emission control, environmental monitoring stations, and biomedical diagnostics. These systems play a crucial role in risk prevention and contribute to sustainable management practices aimed at reducing pollution and protecting public health. Overall, portable smart-sensor-based VOC monitoring technologies represent a promising direction for future research and innovation.

Keywords. Volatile organic compounds, portable monitors, smart sensors, internet of things, monitoring system.

Resumen. El monitoreo eficiente de compuestos orgánicos volátiles (VOCs) se ha convertido en una prioridad esencial en ámbitos como la protección ambiental, la salud ocupacional y la seguridad industrial, debido a su impacto significativo en la calidad del aire y el bienestar humano. Este artículo ofrece una revisión detallada de los avances recientes en sistemas portátiles de monitoreo que incorporan tecnologías de sensores inteligentes para la detección de VOCs. El progreso en la miniaturización de sensores, los algoritmos avanzados de procesamiento de señales y el diseño electrónico de bajo consumo ha permitido el desarrollo de dispositivos compactos capaces de realizar mediciones en tiempo real con altos niveles de sensibilidad y selectividad química. Asimismo, la integración de estos sistemas en arquitecturas de Internet de las Cosas ha ampliado su funcionalidad, permitiendo la transmisión continua de datos, la gestión remota de dispositivos y la aplicación de análisis predictivos mediante plataformas de Big Data. Estas capacidades no solo mejoran la detección temprana de exposiciones peligrosas, sino que también respaldan la vigilancia ambiental a gran escala y la optimización de procesos industriales. A pesar de estos avances tecnológicos, persisten diversos desafíos. Problemas relacionados con la calibración a largo plazo de los sensores, las interferencias ambientales, la confiabilidad de los datos y la eficiencia energética continúan limitando su adopción generalizada. Además, garantizar la interoperabilidad entre distintos protocolos de comunicación y mantener estándares adecuados de ciberseguridad son consideraciones críticas para futuras implementaciones. Esta revisión también presenta la creciente variedad de aplicaciones de los monitores portátiles de VOCs, que incluyen la evaluación de exposición laboral, el control de emisiones industriales, las estaciones de monitoreo ambiental y los diagnósticos biomédicos. Estos sistemas desempeñan un papel fundamental en la prevención de riesgos y contribuyen a prácticas de gestión sostenible orientadas a reducir la contaminación y proteger la salud pública. En conjunto, las tecnologías portátiles de monitoreo de VOCs basadas en sensores inteligentes representan una dirección prometedora para futuras investigaciones e innovaciones.

Palabras clave. Compuestos orgánicos volátiles, monitores portátiles, sensores inteligentes, internet de las cosas, sistema de monitoreo.

1. Introduction

In recent decades, volatile organic compounds (VOCs) have taken on a central role in environmental, biomedical, and industrial studies due to their high reactivity, volatility, and ubiquity in various environments (Schweizer-Berberich et al., 1999). These substances exhibit high vapor pressure at room temperature, which facilitates their release into the atmosphere from both natural and anthropogenic sources, including industrial processes, household products, vehicular emissions, and biological activities (Cheah et al., 2022).

Prolonged exposure to VOCs has been associated with adverse effects on human health, including respiratory diseases, neurological disorders, and certain types of cancer, especially in enclosed spaces or work environments with insufficient ventilation. Furthermore, the accumulation of these compounds in the atmosphere contributes to the formation of tropospheric ozone and other secondary pollutants, exacerbating air quality issues and generating significant environmental impacts.

In industrial contexts, the uncontrolled presence of VOCs can pose critical safety risks, compromise product quality, and result in economic losses due to leaks or inefficient processes. Therefore, efficient monitoring has become a strategic necessity for complying with environmental regulations and preventing hazardous situations. This increasing attention to VOCs has driven the development and implementation of technological solutions aimed at real-time and high-precision detection (Broday & The Citi-Sense Project Collaborators, 2017).

Conventional analytical methods for detecting and quantifying VOCs, such as gas chromatography-mass spectrometry (GC-MS), Fourier-transform infrared spectroscopy (FTIR), and ion mobility spectrometry (IMS), have long been the standard references in chemical analysis of contaminated environments. These techniques are renowned for their high sensitivity, selectivity, and ability to identify a wide range of compounds in complex matrices.

However, despite their analytical strengths, these methods have multiple limitations that hinder their use in scenarios requiring continuous, real-time, and field-based monitoring. Most of this equipment is bulky, expensive, and requires specialized infrastructure for operation, making it unsuitable for portable use or deployment in remote or hard-to-reach locations. Furthermore, they demand highly trained personnel and involve sample preparation, calibration, and rigorous maintenance protocols.

Another major drawback is their limited capacity for immediate response. The time needed for data collection, processing, and interpretation can range from several minutes to hours, reducing their effectiveness for early leak detection, transient events, or chemical emergencies. Likewise, high operating costs and dependence on reagents or analytical standards restrict their use in large-scale continuous monitoring systems.

In response to these challenges, the development of more versatile and efficient solutions has emerged. Portable monitoring systems equipped with smart sensors represent a promising alternative that enables rapid, non-invasive, and cost-effective detection of VOCs, opening new opportunities for medical, environmental, and industrial applications.

Driven by the limitations of traditional analytical techniques, the development and adoption of smart portable sensors for VOC detection have accelerated. These compact, autonomous, and low-energy devices enable real-time environmental monitoring with high spatial resolution, making them essential tools for industrial surveillance, occupational safety, public health, and emission control in urban and industrial zones.

Considering the growing demand for efficient and accessible solutions for VOC detection, this narrative review aims to explore and synthesize the current state of technological development surrounding portable monitors with smart sensors, focusing on their applications in environmental, industrial, and medical monitoring.

The focus of this review is to examine recent advances in miniaturized sensors, integrated detection systems, real-time analytical methodologies, and wireless communication platforms used in portable devices for VOC detection. In addition, the advantages, limitations, and remaining technical challenges are analyzed, particularly in terms of sensitivity, selectivity, operational stability, and response to environmental interferences. Furthermore, this work seeks to identify emerging trends such as the incorporation of artificial intelligence, the use of nanocomposite materials, and the integration with Internet of Things (IoT) technologies, which are revolutionizing how volatile gas pollutant surveillance is conducted. Thus, this review aims to provide an up-to-date overview for researchers and professionals interested in the design, implementation, or evaluation of smart portable VOC monitoring systems.

2. VOCs: Sources, Impacts, and the Need for Monitoring

2.1 Nature and Classification of VOCs

VOCs are chemical substances with high vapor pressure and low water solubility, allowing them to volatilize easily at room temperature. Their origin can be anthropogenic, as in industrial processes, use of paints, fuels, and cleaning products, or biogenic, such as natural emissions from vegetation (e.g., isoprene and monoterpenes), which actively participate in atmospheric dynamics (Horvat et al., 2025).
From an environmental perspective, VOCs play a key role in the formation of tropospheric ozone and secondary particles, negatively impacting air quality and contributing to climate change. In urban and industrial settings, their constant release leads to hazardous accumulations that affect both human health and ecological balance.

2.2 Effects on Human Health

Multiple studies have shown that prolonged exposure to VOCs can cause adverse effects on the respiratory, neurological, and reproductive systems. Certain compounds such as toluene, xylene, and n-hexane—commonly found in paints and solvents—may cause symptoms ranging from dizziness and headaches to chronic liver, kidney, or neurological damage, depending on exposure level and duration.

Even when concentrations are below permissible threshold limits, cumulative exposure can pose significant risks for workers in enclosed environments. For this reason, international organizations such as the WHO and national occupational health agencies recommend the use of updated emission inventories and the implementation of both technical and administrative control measures.

2.3 Definition of VOCs and Examples

VOCs are a broad family of carbon-containing chemical substances that, due to their high vapor pressure, readily evaporate at room temperature. This volatility allows them to rapidly diffuse into the air, where they can participate in photochemical reactions that affect air quality and human health.
According to international bodies such as the Environmental Protection Agency (EPA), any organic compound with a vapor pressure exceeding 0.01 kPa at 20°C is classified as a VOC. Among the most common are:

- **Benzene**: a known carcinogen found in fuels and solvents.
- **Toluene**: used in paints and lacquers, with neurotoxic effects.
- **Formaldehyde**: released from construction materials and textiles; highly irritating and classified as a carcinogen.
- **Xylene**: a solvent widely used in the paint industry.
- **n-Butyl acetate, ethyl alcohol, hexane**: frequently detected in industrial environments involving solvent use.

In environmental contexts, there are also biogenic VOCs, such as isoprene and monoterpenes, emitted by vegetation in response to climatic stimuli. These non-methane compounds also contribute to atmospheric processes like tropospheric ozone formation and secondary aerosol generation.
VOCs are recognized not only for their impact on air quality but also for their potential bioaccumulation and environmental persistence.

2.4 Health and Environmental Effects

Exposure to VOCs poses significant risks to both human health and the environment. Various studies have shown that inhaling high concentrations or experiencing prolonged exposure to specific VOCs can lead to adverse effects on the respiratory, nervous, and cardiovascular systems. Common symptoms in exposed workers include eye irritation, headaches, nausea, dizziness, and, in severe cases, neurological disorders or chronic illnesses such as asthma and cancer (Buelvas et al., 2023).
In environmental terms, VOCs contribute to the formation of tropospheric ozone and photochemical smog, affecting air quality and causing harmful effects on vegetation, aquatic ecosystems, and biodiversity. Additionally, some VOCs are precursors to fine particulate matter (PM2.5), worsening air pollution and climate change issues (Lorenzo-Sáez et al., 2021).
For these reasons, early detection and emission control of VOCs are considered top priorities in public health and environmental protection policies.

2.5 Key Sectors: Health, Chemical Industry, and Environmental Safety

Monitoring VOCs through portable systems equipped with smart sensors is of particular interest in several critical sectors:

- **Occupational and Public Health**: In hospitals, laboratories, and industrial settings, monitoring air quality is crucial to prevent exposure of patients, workers, and the general population to toxic pollutants. These systems help comply with international hygiene and environmental health standards (Benammar et al., 2018).
- **Chemical and Manufacturing Industry**: In industrial processes involving the handling or production of chemical substances, VOC control is essential to ensure worker safety and prevent

accidents from leaks or unexpected emissions. Real-time detection also supports immediate operational decision-making (García et al., 2022).

- **Environmental Safety**: Portable systems enable rapid assessments during environmental emergencies, such as chemical spills or industrial fires. They are also used in urban and rural air quality studies, helping to identify emission sources and verify compliance with legal emission limits (Banerjee, 2023).

The advancement of these technologies directly benefits these sectors by improving risk response capabilities and optimizing prevention and mitigation strategies.

3. Sensing Technologies for VOC Detection

3.1 Types of Sensors Used to Detect Volatile Organic Compounds

According to Alcivar Rosero, electrochemical sensors are a widely used technology for detecting volatile organic compounds due to their high sensitivity and ability to measure low concentration levels. These sensors operate through chemical reactions that generate an electrical signal proportional to the concentration of the detected compound

Similarly, the study by TFG Carreras Moreno highlights that optical sensors provide an effective alternative based on techniques such as spectroscopy and light absorption. These sensors allow for rapid and non-invasive detection, especially useful in environmental monitoring scenarios where real-time response is required.

Lastly, Lamarca emphasizes the development of nanostructure-based sensors, which—thanks to their physical and chemical properties at the nanoscale—increase the active surface area and improves the selectivity and sensitivity of detection. These nanomaterial-based sensors allow for the detection of compounds with higher accuracy and at very low concentration levels, making them promise for industrial and environmental applications.

3.2 Advances in Low-Cost Portable Sensors

Alcivar Rosero states that the development of portable sensors has progressed significantly due to the implementation of miniaturized electrochemical technologies, enabling low-energy consumption and high-sensitivity devices. These sensors have become more economically accessible, facilitating their use in the field for continuous and real-time monitoring.

The work by TFG Carreras Moreno highlights the use of optical sensors integrated into mobile devices, which leverage technologies such as absorption spectroscopy and fluorescence. These advancements have enabled sensors to become more compact and efficient, reducing costs without compromising detection quality

On the other hand, Lamarca emphasizes that the incorporation of nanostructured materials into portable sensors has been key to improving sensitivity and selectivity, by increasing the surface area for compound interaction. This, combined with the integration of smart data processing systems, has boosted the development of affordable and highly reliable portable sensors.

3.3 Integration with Smart Platforms and IoT

The integration of smart systems with the IoT is a fundamental axis in transforming processes both in library environments and in industrial manufacturing. In the context of university libraries, this integration enables automation of key processes such as collection management, resource usage monitoring, and user interaction. New library service platforms are designed to operate under open architectures capable of connecting with sensors, mobile devices, and external systems through robust APIs, facilitating unified, flexible, and real-time data-driven management.

In the industrial sector, IoT has become an essential tool within Industry 4.0. Its integration with intelligent platforms allows machines, sensors, and control systems to connect within an interconnected network that collects and analyzes large volumes of operational data. This synergy has significantly enhanced production efficiency, predictive maintenance, and real-time traceability. Technologies such as cyber-physical systems, combined with data analytics and 5G communication networks, are revolutionizing manufacturing by offering adaptable, secure, and autonomous environments.

Moreover, this convergence between IoT and smart platforms is fostering the development of more sustainable and personalized solutions. In libraries, this translates into optimized energy usage, automated HVAC systems, and improvements in digital accessibility. In the industrial sector, it has enabled waste reduction, emission control, and continuous monitoring of environmental and operational parameters, aligning with global sustainability and competitiveness goals.

3.4 Technical Limitations of Current Sensors

Despite technological advances that have increased access to VOC monitoring, limitations still persist. These include selectivity challenges when dealing with gas mixtures, sensor drift over time, frequent calibration requirements, and dependency on physical environmental factors such as humidity and temperature (Hussain et al., 2024). Furthermore, the use of low-cost sensors often entails reduced precision compared to laboratory-grade analytical equipment.

In this context, research efforts are focused on improving the performance of these devices using advanced materials, artificial intelligence for processing complex signals, and self-calibration systems that extend operational life and reliability.

4. Portable Monitoring Systems and Smart Networks

The evolution of environmental and occupational monitoring systems has led to the development of portable solutions integrated with smart networks, capable of providing continuous, real-time surveillance with high spatial and temporal resolution. These advances enable the efficient detection of VOCs and other pollutants, facilitating decision-making in industrial, environmental, and biomedical settings.

4.1 Architecture of Portable Monitoring Systems

Modern portable monitoring systems are composed of miniaturized sensor modules, data processing units, and wireless communication systems. These devices, typically powered by high-efficiency batteries, can operate in various environmental conditions while recording VOC concentrations with high sensitivity and selectivity (Hernández-Gordillo et al., 2021).

Moreover, the integration of microcontrollers and signal processing algorithms has allowed for reduced energy consumption, increasing the operational autonomy of the devices. These systems are designed with durable and ergonomic casings, making them easy to carry and handle by field personnel or operators.

4.2 Connectivity and Smart Networks

The advancement of wireless communication technologies such as Wi-Fi, Bluetooth, ZigBee, and LPWAN (Low Power Wide Area Network) has enabled portable monitoring systems to efficiently connect to cloud-based data management platforms. This connectivity allows for remote access to collected data, enabling trend visualization and the generation of early warnings when VOC exposure reaches critical levels (Ullah et al., 2024).

Smart networks facilitate interoperability among multiple devices, creating a distributed sensor network that provides a dynamic, real-time air quality map (Lanzolla & Spadavecchia, 2021). These sensor networks can be managed through specialized software that includes predictive analysis and pollutant dispersion modeling functions.

4.3 Integration with IoT Platforms and Big Data

The integration of portable monitoring systems into the IoT ecosystem has revolutionized environmental data management. The mass collection of information and its subsequent analysis through Big Data platforms enables the identification of long-term exposure patterns and the large-scale assessment of occupational risks (Buelvas et al., 2023).

These platforms leverage artificial intelligence and machine learning techniques to process large volumes of data, optimizing the detection of anomalous events and supporting real-time decision-making (Hamza et al., 2022).

4.4 Benefits and Limitations of Smart Monitoring Networks

The main benefits of smart monitoring networks include:

- **Greater spatial coverage**: The deployment of multiple portable sensors provides a more comprehensive view of the environment (Lorenzo-Sáez et al., 2021).
- **Real-time alerts**: Instant data communication enables the implementation of rapid response systems in hazardous situations (Benammar et al., 2018).
- **Historical analysis**: Cloud-based storage platforms allow for retrospective data analysis to identify exposure trends (Banerjee, 2023).

However, these networks also face certain limitations, such as dependence on wireless connectivity, the need for efficient energy management in portable devices, and the requirement for periodic calibration to ensure measurement accuracy (Hong et al., 2023).

4.5 Industrial and Environmental Applications

The use of portable monitoring systems and smart networks is increasingly common in industries such as manufacturing, petrochemicals, mining, and occupational health. These technologies are also employed in urban air quality studies, vehicular emissions control, and environmental impact assessments of emission sources (García et al., 2022).

The implementation of these systems significantly contributes to workplace risk prevention, compliance with environmental regulations, and public health protection (Kortoçi et al., 2022).

5. Current Challenges and Future Trends

5.1 Technological Transition and Resistance to Change

One of the main current challenges in the digitalization of libraries and industrial environments is organizational resistance to adopting new technologies. Although cloud computing, software as a service (SaaS), and library service platforms offer efficient and integrated solutions, many institutions continue to use legacy systems that hinder interoperability and limit innovation opportunities. Similarly, in the manufacturing sector, the implementation of technologies such as AI and advanced robotics faces cultural, economic, and technical barriers, especially in small and medium-sized enterprises lacking specialized personnel and sufficient resources (Hussain et al., 2024).

5.2 Cybersecurity and Data Protection

As library and industrial systems become interconnected via IoT networks and digital platforms, cybersecurity has become a critical priority. University libraries, when integrating remote services and digital repositories, are exposed to vulnerabilities that require robust and up-to-date solutions. Likewise, in manufacturing, protecting production systems against cyber threats is essential. The use of industry-specific security protocols and AI-based detection systems is becoming common practice to mitigate these risks.

5.3 Unequal Technological Infrastructure

The availability of digital infrastructure—such as high-speed internet, cloud servers, and scalable platforms—is not yet guaranteed in all regions, creating significant technological gaps. Many libraries, especially in rural areas or developing countries, face limited access to modern technologies, hindering their transition to more efficient automation and knowledge access models. Likewise, manufacturing industries in regions with limited infrastructure face major obstacles to implementing intelligent production systems, slowing down their global competitiveness.

5.4 Trend Towards Technological Sustainability

Both libraries and industrial environments are positioning sustainability as a central future trend. Libraries are migrating to digital platforms that minimize the use of physical resources and optimize storage and access to digital content, thereby reducing energy consumption. Concurrently, in manufacturing, technologies such as additive manufacturing, smart energy management, and the use of recyclable materials contribute to reducing the carbon footprint and fostering circular economy models.

5.5 Evolution Towards Intelligent Automation

Finally, the clearest trend in both sectors is the evolution towards intelligent automation. In the library field, the use of enriched metadata, integrated discovery systems, and semantic search engines is transforming how users access information. In industry, technologies like digital twins, Blockchain, and collaborative robots are generating new possibilities to optimize production, predict failures, and increase product personalization without sacrificing efficiency.

6. Conclusions

The review conducted on portable systems with intelligent sensors for the detection of volatile organic compounds shows significant progress in the field of environmental and occupational monitoring. The state of the art reflects continuous advancements in sensor miniaturization, improved sensitivity and selectivity, as well as the integration of connectivity technologies and real-time data analysis. Despite these advances, there remains a clear need to continue developing systems that are more precise, economically accessible, and with greater operational durability. Overcoming current challenges related to calibration, energy autonomy, and compound interference will be essential to ensure their effectiveness and applicability across different environments.

The importance of real-time monitoring lies in its ability to generate early warnings, prevent environmental risks, and protect the health of individuals exposed to hazardous contaminants. The implementation of these technologies not only strengthens industrial safety management but also contributes to environmental sustainability and compliance with international air quality regulations. In this context, continuous innovation and collaboration among industry, academia, and government entities will be key to developing more efficient and sustainable technological solutions in the future.

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