



Editorial

Agricultural Sensors: Empowering Intelligent and Sustainable Agriculture



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Agriculture is entering a new era in which the ability to sense biological processes, environmental dynamics, product quality, and operational risks in real time is becoming as essential as the ability to cultivate, manage, and harvest. As global food systems face mounting pressures from climate change, resource scarcity, environmental pollution, labor shortages, and the rising demand for safe and high-quality agricultural products, agricultural sensors are emerging as a foundational technology for modern agriculture. By enabling the timely, precise, and scalable acquisition of information from soil, plants, animals, agricultural products, and farming environments, sensors provide the perceptual basis for data-driven decision-making, intelligent equipment, and sustainable production.

Among the many enabling technologies for smart agriculture, agricultural sensors hold a particularly central position. They connect the physical, chemical, and biological states of agricultural systems with digital intelligence, allowing previously invisible processes to be measured, interpreted, and managed. From greenhouse gas emissions and soil nutrients to intracellular signaling molecules in plants, from the spectral imaging of crops and fruits to spoilage monitoring in meat and obstacle perception for autonomous agricultural machinery, sensor technologies are continuously expanding the boundaries of agricultural observation and intervention. Their development is not only advancing precision agriculture but also reshaping agricultural science, equipment,

and industry through the convergence of materials science, optics, electronics, artificial intelligence, and robotics.

To highlight recent advances in this rapidly evolving field, we are pleased to present this special issue, titled “Agricultural Sensors.” The issue includes one review, one views & comments, and five original articles, each addressing an important dimension of sensing science and technology for agriculture:

- Rastgou et al. [1] systematically compare sensing materials and detection mechanisms for greenhouse gas monitoring, offering a valuable analytical framework for selecting sensor strategies suited to agricultural emission measurement and environmental management.
- Zhang et al. [2] report an implantable, self-powered sensing system capable of continuously monitoring hydrogen peroxide levels in plants *in vivo*. By integrating a photovoltaic module with an implantable microsensor, the work provides an innovative tool for resolving the temporal and concentration-specific dynamics of signaling molecules under abiotic stress, opening new opportunities for plant physiology research and stress-resilient crop breeding.
- Dong et al. discuss the urgent need for the rapid and reliable in-field sensing of soil nutrients and highlights recent progress in soil sensing technologies. It underscores the strategic importance of sensor innovation for soil fertility management, precision fertilization, and food security.
- Tang et al. propose an unsupervised degradation-aware super-resolution network to improve the spatial quality of low-resolution spectral images without paired training data. The study demonstrates how computational sensing and artificial intelligence can compensate for hardware limitations and strengthen crop phenotyping and remote sensing applications across devices, scales, and regions.
- Gao et al. present a continuously tunable wavelength spatial frequency domain imaging system spanning 450–1040 nm. By moving beyond fixed multispectral configurations toward customizable, spectrally continuous imaging, the work establishes a new paradigm for nondestructive fruit-quality evaluation and broadens the applicability of optical property sensing in agricultural products.

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- Hu et al. develop a microwave ammonia sensor with machine learning-based compensation for temperature and humidity fluctuations in cold-chain environments. The study provides a practical and robust approach for the non-destructive monitoring of fresh meat spoilage, highlighting the importance of sensor intelligence in maintaining food quality and safety.
- Wang et al. introduce a multimodal three-dimensional (3D) obstacle-detection method for agricultural machinery that reduces dependence on large annotated datasets. By integrating camera and light detection and ranging (LiDAR) information and addressing few-shot and zero-shot scenarios, the work provides an effective sensing solution for safer and more reliable autonomous navigation in complex field environments.

Taken together, these contributions reflect several important frontiers in agricultural sensing, including the following areas:

- Environmental and ecological sensing, covering greenhouse gas emissions and soil nutrient monitoring, which are essential for climate-smart agriculture, sustainable input management, and ecological protection;
- Plant and crop sensing, including the implantable monitoring of plant signaling molecules and enhanced spectral imaging for crop phenotyping, which deepen our understanding of plant responses and improve precision crop management;
- Agricultural product quality sensing, represented by the advanced optical imaging of fruits and microwave sensing of fresh meat spoilage, which extend sensor applications from production to postharvest quality evaluation and cold-chain monitoring;

- Intelligent sensing for agricultural machinery, represented by multimodal 3D obstacle detection, which strengthens the perceptual foundation for autonomous agricultural operations.

This special issue also reveals a broader technological trajectory in agricultural sensors: from single-parameter detection to multimodal perception, from offline measurement to continuous and *in situ* monitoring, from passive observation to intelligent interpretation, and from standalone devices to integrated sensing systems coupled with machine learning, autonomous platforms, and decision support. Such transformations are expanding the role of sensors from measurement tools into core infrastructure for digital and intelligent agriculture.

We believe that the studies presented in this special issue will advance the science and engineering of agricultural sensing; stimulate further innovation in sensing materials, devices, and algorithms; and accelerate the translation of sensor technologies into real-world agricultural applications. More importantly, these studies demonstrate how agricultural sensors can serve as a strategic bridge linking fundamental discovery, technological innovation, and industrial deployment, thereby supporting the development of productive, resilient, and sustainable agriculture.

References

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- [2] Zhang C, Wu X, Yao S, Shao Y, Zhang C, Zhou S, et al. An implantable and self-powered sensing system for the *in vivo* monitoring of dynamic H₂O₂ level in plants. *Engineering* 2026;56:332–40.