

AI Vision in Agriculture: Applications, Innovations, and Future Trend

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Introduction

We are currently experiencing the *Industrial Revolution 4.0*, an era defined by the seamless integration of digital technologies, automation, and data exchange within manufacturing and industrial systems. This transformation is driven by key technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and Machine Learning, Big Data and Analytics, Cyber-Physical Systems (CPS), Cloud Computing, Advanced Robotics, 3D Printing, Augmented and Virtual Reality (AR/VR) and Cyber security. Together, these innovations are reshaping industrial operations, making them more intelligent, interconnected, and efficient than ever before. Simultaneously, the agricultural sector is undergoing a significant transformation through *Agriculture Revolution 4.0*, also known as Smart Agriculture or Digital Agriculture. This revolution is driven by the integration of advanced digital technologies, automation, and data-driven decision-making into farming practices, largely influenced by the developments of *Industrial Revolution 4.0*. *Agriculture 4.0* marks a major advancement from conventional methods, driven by digital innovation in farming. The areas discussed below are presented to provide insights for the readers.

Sensors play a crucial role in modern agriculture, enabling real-time monitoring and data-driven decision-making. Various types of sensors, such as soil, weather, plant, and water sensors, are being deployed to gather critical field data. This information supports predictive analytics and helps optimize the application of agricultural inputs. Soil sensors are primarily used to measure moisture, temperature, pH, salinity, and nutrient levels, providing essential insights for effective soil and crop management. Weather sensors are equally important, as weather conditions directly influence agricultural outcomes. These sensors track parameters such as temperature, humidity, rainfall, wind speed, and solar radiation, all of which are vital for achieving sustainable farming practices. Plant sensors monitor

factors like crop health, chlorophyll content, and stress levels, allowing for early detection of issues and timely interventions. Another critical area in water resource management is the use of sensors and IoT technologies to ensure optimal water usage and application efficiency. Smart irrigation systems have been developed by integrating data from soil moisture sensors and weather forecasts, allowing for automated and precise water distribution based on real-time field conditions. Additionally, IoT-based sensors provide continuous, real-time data that supports precise planning and resource allocation. By enabling better control over the use of water, fertilizers, and pesticides, sensor technologies help improve yields and crop quality, reduce input costs, and minimize environmental impact, ultimately contributing to more efficient and sustainable agriculture.

Agricultural machinery (tractors, harvesters, sprayers, and irrigation systems) are now equipped with equipment sensors that collect real-time data on performance, fuel consumption, and GPS location. These sensors enable detailed evaluation of machine operations by providing insights into both functional and environmental conditions. Ultimately, they support autonomous machinery operations, enhance efficiency, and reduce downtime through predictive maintenance. Using AI to analyse large datasets allows for more precise and informed decision-making, which is fundamental to precision farming. Sensor data can be integrated into farm management systems to support broader, data-driven decisions. The data collected from various sources becomes a valuable asset, and its application can lead to significant improvements in efficiency and productivity. It helps optimize the use of fuel, time, and resources, ultimately saving money and minimizing environmental impact. The immense potential of data gathered from sensors, drones, satellites, weather stations, and machinery provides the foundation for advanced computing, enabling the extraction of meaningful patterns and insights.

Efficient post-harvest management of agricultural produce is vital and holds substantial

commercial value. Notably, the integration of blockchain technology and artificial intelligence is enhancing product traceability, thereby promoting greater transparency throughout the food supply chain. These technologies improve food safety, reduce spoilage, keep products fresh, and help maintain quality from farm to consumer. To maintain product quality from the farm to the end consumer, continuous monitoring is essential for managing and optimizing each stage of the supply chain. Supply chain sensors enable accurate monitoring and control of environmental conditions. Temperature and humidity, during the storage and transportation of agricultural produce. Ethylene gas sensors help track the ripening process, while CO₂ and O₂ sensors are used to monitor the atmospheric composition in storage, improving food handling and shelf life. Vibration sensors detect physical shocks or impacts during transit, helping identify potential damage. Location tracking technologies, such as GPS and RFID/NFC tags, support traceability by providing real-time information on the movement of goods. Optical sensors play a key role in inspecting the quality of post-harvest commodities, contributing to improved food safety and quality control. These sensors enable tracking changes and to evaluate the cause of deterioration. Real-time data enables timely interventions and corrective actions, enhancing food handling practices aiding to preserve the quality of agricultural products.

The use of IoT sensors for real-time monitoring of livestock health and management is an essential aspect of modern farming, where the role of AI is increasingly significant. Sensors and tracking devices continuously collect vital data such as body temperature, heart rate, and activity levels. AI algorithms analyze this information to detect early signs of illness, allowing for timely intervention and improved animal care. AI is also used to assess feeding habits, resting times, and movement patterns, identifying behavioral changes that may indicate stress or health issues. Feeding management is another critical application, where data on an animal's weight, age, and nutritional needs is processed by AI systems to determine precise feed portions, reducing waste and ensuring optimal growth. In reproduction management, AI analyzes hormonal changes, temperature, and behavioral patterns to predict the best breeding times. This improves conception rates

and helps schedule calving more effectively. AI-integrated smart milking systems can detect issues such as mastitis, monitor milk yield per cow, and ensure consistent, low-stress milking, reducing labor requirements. Additionally, livestock tracking and identification are carried out using facial recognition or RFID tags combined with AI, enabling detailed tracking of individual animals. AI systems also monitor barn conditions such as temperature, ventilation, and humidity to maintain a healthy environment and support overall animal welfare.

Technologies such as drones and satellite imagery are increasingly being utilized in agriculture, revolutionizing the sector by enabling precise, real-time monitoring and data collection over large farming areas. Drones, or Unmanned Aerial Vehicles (UAVs), are particularly effective for crop monitoring, capturing high-resolution aerial images that provide valuable insights into plant health, physical structure, pest infestations, field stress, and nutrient deficiencies. These high-quality images whether captured by drones or satellites reveal details that are often not visible through ground-based observation. As aerial platforms, drones also facilitate detailed field mapping, offering crucial information on cropping patterns and overall farm conditions. A key current application of drones is in precision spraying, where fertilizers or pesticides are applied specifically to target areas under optimal conditions. This targeted approach reduces input waste and minimizes environmental impact. Additionally, drones are being explored for tasks such as seed planting and managing agricultural operations in remote or difficult-to-access regions. Satellite imagery, when integrated with AI and GIS technologies, provides valuable insights that support soil moisture monitoring and crop forecasting. High-resolution images (Multispectral, thermal, LiDAR) captured across multiple spectral bands are used to evaluate plant health using vegetation indices such as the Normalized Difference Vegetation Index (NDVI).

The role of automated machinery in tasks such as planting, harvesting, and irrigation is vital in modern agriculture. The use of machines to perform repetitive and labour intensive tasks has paved the way for the integration of robotics, known for their high-precision operations. This technology significantly enhances efficiency and contributes to increased productivity. Robotics particularly address

the problems related to labour shortages and reduces the physical burden of manual work, making farming more manageable and less dependent on human labour. Moreover, automation supports sustainable agricultural practices by optimizing resource use and minimizing waste. Key applications include automated planting, where seeders and planters accurately place seeds at specific depths and spacing. This precision improves germination rates and ensures uniform crop growth. In weeding, robots equipped with mechanical arms can remove weeds or apply targeted herbicides, often using AI and imaging systems for targeted herbicide spraying. Robotic arms used for harvesting are designed to pick agricultural produce efficiently while reducing the need for human labour. By integrating sensors with AI, these systems can identify ripe crops, navigate the fields, and perform precise harvesting, marking a significant advancement in agricultural automation. Robotic arms are widely used for milking in dairy farming, offering automated solutions that are now common across the globe. These systems help reduce animal stress during the milking process and significantly lower the need for manual labour. Overall, robotics and automation are transforming traditional farming into a technology-driven industry, making agriculture more productive, scalable, profitable, and sustainable.

Conclusion

In summary, *Agriculture 4.0* focuses on automation, precision, and data-driven decision

making through high-tech tools aimed at improving efficiency. Looking ahead, *Agriculture 5.0* marks a shift toward a human-centered, sustainable, and resilient farming system that integrates advanced technology with environmental and social goals. There is also a growing emphasis on sustainable and climate-resilient agriculture. Practices like regenerative farming improve soil health and carbon sequestration, while circular systems help reuse resources efficiently. These approaches contribute to climate-smart agriculture, which includes predicting climate risks, optimizing planting schedules, and managing extreme weather impacts. This transition empowers farmers to work alongside AI-driven equipment and take part in decision-making. However, improving digital literacy is essential to ensure they can fully engage with these tools. Farm-specific solutions, powered by AI and real-time data, will play a key role in enhancing productivity and profitability. Special attention must be given to engaging women, youth, and underserved communities by making agriculture more inclusive and rewarding. This includes stronger efforts in knowledge transfer, practical training, and developing user-friendly digital platforms and apps. Achieving these goals will require collaboration among governments, research institutions, startups, and farmer groups, along with policy support and incentives for adopting sustainable and inclusive innovations.
