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Convergence of AI, IoT, and Robotics in Smart Agriculture for Next-gen Engineering Education

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***Abstract*— This paper discusses the emergence of convergence of Artificial Intelligence (AI), Internet of things (IoT) and robotics on smart agriculture and presents the role of the convergence on next-generation engineering education. The study illustrates the advantages of using smart agriculture as an application domain for enhancing the present-day engineering education through application of learned new IT & communication tools for automation and data mining usages. The application domain of smart agriculture is used as an example to illustrate how real-time information collection, predictive analytics, and automated systems can be applied into engineering education curricula to improve practical and interdisciplinary skills of the students.**

***Keywords* - robotics, Internet of Things (IoT), agriculture 4.0, artificial intelligence (AI), and smart farming/smart agriculture.**

I. INTRODUCTION

Agriculture is the largest sector of Indian economy and also the lowest contributing sector to the GDP growth. By 2050, there will more people and the need of food requirements should be increased by 70%. Traditional agriculture is about to deal with and is unpredictable with many reasons like post-harvest loss, water stress, nutrition deficiency, poor infrastructure connections, soil degradation and information interruption by Sharma et al. (2024); Abbasi et al. (2022); Assimakopoulos et al. (2024). Computer science has been come in agriculture decades ago, mainly artificial intelligence. It is the recent technology that has been increasing contribution in agriculture sector such as using effective farming practices among wide crop types so that humanity is still surviving after thousands of years. The new AI technology ensures high-quality products and continuously monitoring of farms ecosystem The wide distribution in farming practices costs several hurdles for smart sustainable agriculture like means to manage and deploying AI technologies, data sharing and governance, interoperability, analyze by Liakos et al. (2018); Benos et al. (2021); Shaikh et al. (2022); AlZubi & Galyna (2023). The author would like to emphasize the necessity of revolutionizing smart farming paradigm for efficient farming performance according to eco-friendly standards.

II. LITERATURE REVIEW

Shaikh, et al. (2022) look into how AI supports smart agricultural practices that support sustainable agriculture. It demonstrates the application of AI to plant growth, disease prediction, weather forecasting, soil and irrigation management, and animal management. Additional research on integrating AI across layers of smart agricultural infrastructure is also recommended by the analysis. An IoT with an ARM processor that automates seed planting and field monitoring is covered by Ragavi et al. (2020). It keeps an eye on the surroundings, lowers labor, and detects animal movements. It combines cloud-based agriculture for data analysis and storage, solar power, and AI sensors with automated seeding. The evolution of AI and other agricultural technologies is examined by Asimakopoulos et al. (2024) Using case studies, technical developments, and recent research, the study provides an overview of smart agricultural technologies. Insights are needed to address global food security concerns, lessen environmental effects, and advance sustainable development for farmers and consumers through cutting-edge technology. The article by Issa et al. (2024) explores the ways in which AI and IoT have changed modern agriculture. The study looks at a cloud-based remote farm monitoring system that analyses data and enhances farming practices using AI-based models. The potential of AI and IoT to revolutionize agriculture (see in Fig. 1), address global food security, and advance sustainable development is covered in this article.

III. RESEARCH METHODOLOGY

A Systematic Literature Review (SLR) approach was adopted to analyze the existing research. The research methodology included defining objectives, selecting sources like IEEE Xplore and Scopus, applying inclusion criteria, and analyzing technologies such as AI, IoT, blockchain, and robotics. Concepts from smart agriculture were mapped to education, including student performance tracking, personalized learning, smart classrooms, and automation in administration. Case studies were also analyzed for practical insights. Academic literature search engines include IEEE Xplore, Scopus, ScienceDirect, and Web of Science Research Questions.

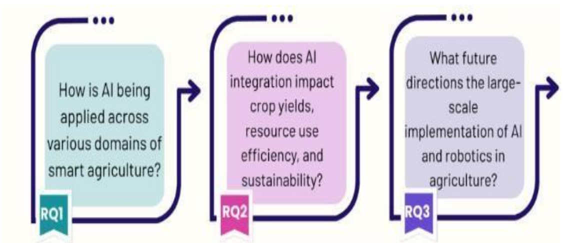


Fig. 1. Framework of Research Questions for AI-driven Smart Agriculture

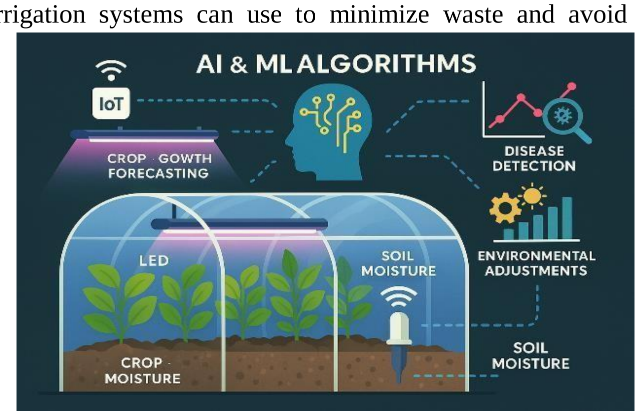
IV. SMART AGRICULTURE

The industry 4.0 or the fourth industrial revolution is transnormal in the way in which each industry is functioning and revolutionizing everything (Abbasi et al. (2022); Aceto et al. (2019); Gacar et al. (2017)). This strategy integrates several innovative cabin digitally disruptive technologies like Additive Manufacturing (AM), Artificial Intelligence (AI), Augmented Reality (AR), Autonomous Robotic System (ARS), Big Data & analytics (BDA), Cloud Computing (CC), Cyber Physical Systems (CPS), Digital Twins (DT), Internet of Things (IoT), system simulation, system integration (SI) and Wireless Seniors Networks (WSN) and aims to facilitate digitization of the fabric industry (Aceto et al. (2019); Abbasi et al. (2022); Assimakopoulos et al. (2024)). Supported agricultural was to provide farmers with the resources they need to combat issues of crop loss, sustainable, food security, and such is the agenda that can take to ensure the improvement of the environment by effective and efficiencies technology systems increasingly popular.

Smart agriculture provides farmers with means to overcome many issues on crop loss, sustainability, food security, environmental consequences and additional productivity issues on farm: -near real-time remote monitoring and control of farming operations with IoT-enabled systems such as WSNs:-pervasive computing for automation and aid on agricultural calculations and decision (Lloret et al. (2021); AlZubi & Galyna (2023)). Instead, UAVs (Velusamy et al. (2022)) with HS cameras can collect information from different sources on agricultural areas. Farms can use automated robots for assistance or performing repetitive jobs, computer systems can support decision-making on farms and data analysis techniques can analyze the collected information-using such, smart agriculture can monitor and analyze wide spectrum of environmental parameters, weed management, availability and conditions of water, crops production status, irrigation scheduling, soil conditions, delivery of herbicides, pesticides, and controlled environment agriculture-contrast administration systems, in order to improve the crop yields, carper cost, improve the quality of the products, conserve the processes' inputs ((Shaikh et al., (2022); Sharma et al., (2024); Pal & Joshi, (2023)).

V. APPLICATIONS IN SMART FARMING

Smart farming, by leveraging the new developments of IoT, AI, and data Analytics, optimizes the productivity of crops, resource utilization, and sustainability. There are two waste and environmental effect issues of environmental sustainability, processed by combined implementation of above three new ventures, reduces wastes usage and related environmental effect ((AlZubi & Galyna, 2023; Abbasi et al., (2022)). Although by reducing water and fertilizer, pesticides concern for resources limit with smart farming to gain production and efficient farming, increasing yields by predicting crop growth trends, enabling early disease diagnosis, and enacting environmental changes, AI & ML algorithms leverage Internet of Things sensor data to improve greenhouse management (see in Fig. 2). To identify optimal plant conditions and increase production and resource efficiency, they examine historical data. To increase farm productivity and the effectiveness of agricultural cycles, machine learning technologies may optimize land use, crop selection, planting schedules, and forecast LED grow light systems installed in green houses determine correct amount of lighting required by plants at appropriate times (van Delden et al. (2021)) Monitor and control soil quality to ensure correct environment is maintained for vegetative growth. Use, for instance, moisture sensors to provide essential data which digital irrigation systems can use to minimize waste and avoid



over irrigating.

Fig. 2. AI and Machine Learning Algorithms for Smart Greenhouse Monitoring and Crop Management

1) *Block chain Technology*

A powerful tool to improve the traceability in the agricultural supply chains, affordable for all players are the block chain technology. Fertilizers, pesticides, and other inputs' provenances of agricultural production, harvesting, processing, storage, transportation records may be stored on the database. This technology builds trust, improves fraud detection, ensures supervision, and facilitates organic and animal welfare certification procedures.

2) IoT and Data Analytics

The Internet of Things enable real time assessment and data collection by the use of sensors placed within homes and farms. These sensors analyze temperature, humidity, nutrients and soil moisture, pathogens and pest levels, crop health, soil, and temperature moisture sensors to conserve water and advance crop growth (AlZubi & Galyna (2023))

i. Drones and Unmanned Aerial Vehicles (UAVs):

Drones and UAVs are widely used in modern agriculture. Drones equipped with high-resolution cameras, multispectral, and hyperspectral sensors can capture detailed aerial footage of fields.

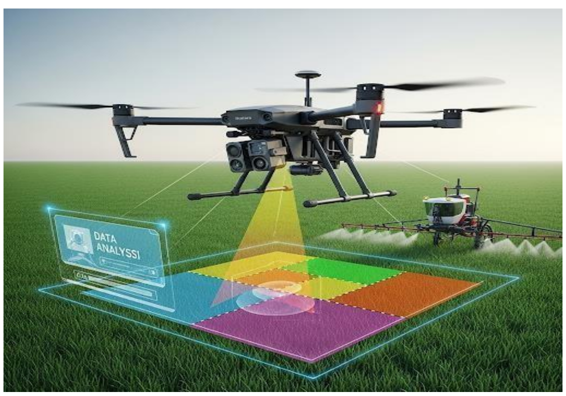


Fig. 3. AI-Powered Drone-Based Smart Agriculture Monitoring System

Crop health, pest infestations, nutrient deficiencies, fruit ripeness, soil composition, etc. are all revealed by this imagery analysis, enabling early detection and focused actions like chemical reduction, precision pesticide or fertilizer spraying, and higher crop yields. Aerial image-based longitudinal studies can demonstrate how regenerative practices improve crop resilience and soil health.

i. Renewable Energy Systems:

energy for farming, cutting costs, using fossil fuels, carbon emissions, and promoting sustainability￼￼Because of the materials required to fully benefit, connecting these devices to the grid or energy storage increases costs and carbon emissions. Sustainable agriculture still depends on these systems, especially when combined with optimization technique

ii. Robotics:

Planting, pruning, harvesting, and packing are among the agricultural tasks that robotics is transforming. These technologies support labor savings, operational efficiency, and precision agriculture. Computer vision systems accurately identify ready produce, while AI-driven robotic systems streamline repetitive tasks and save labor costs. Ripe products can be precisely located and harvested by robotic systems that use AI algorithm (Ragavi et al. (2020), Pal & Joshi (2023))

VI. CASE STUDY

A. Project Overview

i. Solar-Based Micro-Irrigation System

Fig. 4. Solar-Powered Smart Irrigation System for Sustainable Agriculture

Location: Tulya Chapada, Mahadevapura, Palghar (Maharashtra) shows how a solar-powered micro-irrigation system might help farmers .Implementing NGO: Pragati Pratishtha System Type: Solar-powered drip irrigation Cost Breakdown (Approx. ₹10.3 Lakhs per system) Head Unit ₹80,872; Submain & Main Line
₹1,94,781; Drip Laterals & Accessories ₹2,27,000+; Solar Pump & PV Panels ₹5,25,750

Beneficiaries: ~50–60% of households; 10 farmer groups (10–11 farmers each). (Technology and Development Solutions Cell [TDSC], Centre for Technology Alternatives for Rural Areas [CTARA], & Indian Institute of Technology Bombay, 2019).

ii. Technical Design Highlights:

Water Source: The Tulya Chapada dam and seepage lines with gunny check dams.
Pump Capacity: 7.5 HP pumps are used to raise water.
Solar Setup: There are 48 solar panels (about 4.9 kWp) set up near the sand filters.
There are four zones in the irrigation layout, each having submains, laterals (16 mm dia), and emitters spaced 0.4 m apart. Total area of around 2.46 hectares; each farmer waters about 0.5 acres.
Application Rate: ~4.1 mm/hr Daily Water Requirement:

~148 corm/day during peak crop season Irrigation time: ~6 hours/day using Sop availability .Zone-wise Operation: Shift-based scheduling to optimize water delivery

iii. Impact & Benefits Highlights:

Water Savings: Up to 50% to 60% less than regular flow irrigation. Crop Suitability: Vegetables, horticultural crops, and farming on hard rock land Community Upliftment: Less migration, more jobs, and more use of technology.
Environmental benefits: using renewable energy and lowering carbon footprint, Drone Applications in Indian Agriculture (Velusamy et al. (2022); Pal & Joshi (2023))

iv. Key use cases

Precision Spraying: Applying pesticides and fertilizers only in necessary areas may reduce chemical use by as much as 30%.
Crop Health Monitoring: Multispectral imaging can detect stress, illness, and nutritional deficits at an early stage.
Field Mapping and Surveying: High- resolution maps facilitate irrigation planning and optimize land use.
Yield Estimation: AI-driven analytics facilitate the prediction of harvest quantities and their subsequent distribution.
Surveillance of animals and the boundaries is advantageous for large farms and remote locations.

Fig. 5. Drone-Based Crop Spraying in Smart Agriculture

v. Impact

Saving Water: Compared to spraying by hand, up to 90% less. Reduction of Chemicals: Pesticide usage can be reduced by 25–50%.Coverage Efficiency: One drone may cover up to 30 acres each day. Better yield: 10 to 15 percent more monitored crops. Cost per Acre s praying ₹650–1,200, depending on the kind of drone.

B) *Sensor-Based Fertigation in Precision Farming for Horticulture*

Sensor-based fertigation uses sensors for soil moisture, nutrients, and climate together with automated drip systems to provide crops the right quantity of water and fertilizers depending on their current requirements (Tedeschi et al. (2021)). This makes sure: Best nutrient absorption Lower costs for inputs better quality and yield there is minimal impact on the environment. Tamil Nadu has emerged as a national leader in the implementation of sensor-based fertigation systems for horticultural crops, mostly due to the Tamil Nadu Precision Farming Project (TNPFP) and the efforts of the Tamil Nadu Agricultural University (TNAU) Precision Farming Development Centre (PFDC) (2024). (PFDC–Tamil Nadu Agricultural University; Lloret et al. (2021); Sharma et al. (2024)).

i. Technology used and Impacts achieved

Capsicum: IoT-enabled fertigation in polyhouses results in 30–40% water conservation and enhanced fruit size. Fertilization of tomatoes and eggplant using deep Q-learning Adaptive irrigation, 30% decrease in inputs. Cabbage subsurface drip irrigation with fogger sensors Regulated environment, increased productivity. Grapes and Pomegranate: Weather-Dependent Fertigation Disease management leads to an increase in sugar concentration.

VII. CHALLENGES

Some of the primary difficulties are as follows, per Some agricultural laborers may lose their jobs because of automation through AI and robots.

i. Ensure smooth transition worker retraining and reskilling strategies are essential.
ii. Difficulties include high upfront costs, data management challenges, complex technology, and the requirement for specialized knowledge and training.
iii. Cloud computing, blockchain technology, IoT devices, and sensitive operational and health data make data security and privacy crucial.
iv. Agriculture is becoming more accessible due to price reductions, improved computer skills, and technological advancements.

VIII. RESULTS

The incorporation of smart technologies improves efficiency and performance. IoT enables real-time monitoring, AI supports resource optimization and personalized learning, and automation reduces manual workload.

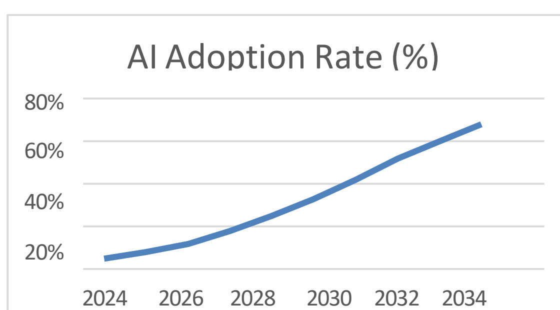


Fig. 6. AI Adoption Rate Over Time (2024–2035)

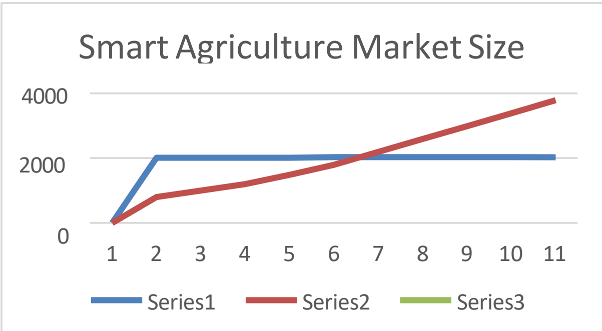


Fig. 7. Smart Agriculture Market Size Growth Trend

Case studies show improvements such as increased efficiency (10–15%) and resource savings (30–60%). The adoption of AI, IoT, blockchain, and robotics can transform education by making systems intelligent and adaptive. Overcoming—though notwithstanding—cost issues of machine learning, information, mining and data security; these technologies improve learning outcomes and institutional efficiency. Future work should focus on scalable and secure smart education systems.

IX FUTRE SCOPE

Agriculture & Satellite Monitoring: Showcase how climate-smart practices and quick assessment tools can be used to increase crop and resource yield.
Soil-First, Carbon-Smart Farming: The Earth5R methodology on organic sustainable agriculture through carbon farming.
Intelligent Farming Wipro's infographic on how data analytics and the Internet of Things are revolutionizing farm management is powered by analytics.
Using AI, drones, and automated irrigation systems, ESDS explains the transition from conventional to tech-driven farming.
Future of Farming: Global Spec's perspective on international smart agriculture trends and India's stance considering the evolving situation.
With a roughly 51% market share in 2024 and a steadily rising 55.5% by 2033, precision farming continues to hold the lead. Over the course of ten years, the Smart Greenhouse segment grew at the fastest rate, rising from 18.2% to 22.5%.

CONCLUSION

Smart farming using AI, IoT and robotics is helping to improve the farming field more effectively & efficiently. Certainly, it is helping engineering education too by preparing students more practically.

Learning the machinery & tool's operation through the use of real time applications like smart farming is helping students in understanding their operation practically. So they are preparing more applicable skills & knowledge for their professional future.

But all these benefits need some of the challenges such as their cost, security of data, need for Specialized expertise & so on, to overcome by suitably & these issues must be resolved to implement the systems more effectively.

Overall, among the various exists for required delivery of education; Smart farming through AI, IoT & robotics showing the best combination in world of Agriculture & Engineering.

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