Smart and Mechanized Agricultural Application

Subjects: Remote Sensing
Contributor: Farzad Kiani , Giovanni Randazzo , Ilkay Yelmen , Amir Seyyedabbasi , Sajjad Nematzadeh , Fateme Aysin Anka , Fahri Erenel , Metin Zontul , Stefania Lanza , Anselme Muzirafuti

Smart farming can be applied to improve crop quality and profit and reduce costs by optimizing various processes such as environmental conditions, growth status, soil status, irrigation water, pest control, fertilizers, weed management, and greenhouse production environments

autonomous robots remote sensing smart agriculture

1. Introduction

Population growth in the world naturally causes an increase in food needs, and with the prediction that the world population will reach nine billion people by 2050, agricultural production should be increased by 70% [1]. Therefore, growing crops becomes very important. However, agricultural practices using traditional methods to meet people's food consumption needs can have quite inefficient results. Therefore, it becomes essential to manage agricultural activities using different advanced methods. Additionally, environmental protection and sustainability have also become basic needs [2]. In this regard, smart farming mechanisms using new technologies have become very popular [3]. It should not be forgotten that not only modern agriculture methods but also sustainable solutions should be proposed. With the creation of efficient solutions to meet identified needs, it may be possible to provide the next generation with a lifestyle at least equal to that of the current generation [4] and to use existing natural resources efficiently in this direction. Otherwise, we may face not only the problem of hunger but also challenges such as energy and migration crises. In summary, problems such as global climate change, increasing conflicts around the world, migration crises, improper use of existing agricultural lands, decrease in precipitation levels, and incorrect use of water all have made the use of modern agriculture systems mandatory.

Technologies such as remote sensing, the Internet of Things (IoT), intelligent agents, autonomous robots, unmanned aerial vehicles (UAVs) [5], Internet of Vehicles (IoVs), wireless ad-hoc networks, big data analytics, and deep learning (DL) have shed light on promising visions for a breakthrough in agricultural applications [6][7][8][9]. Smart farming can be applied to improve crop quality and profit and reduce costs by optimizing various processes such as environmental conditions, growth status, soil status, irrigation water, pest control, fertilizers, weed management, and greenhouse production environments [10]. For example, questions such as which product should be planted in a given region, how efficient the use of water resources should be, and accurate estimation of the harvest time all can be answered and monitored in smart agriculture. Thus, smart agriculture ensures green technology by eliminating the inefficient and faulty methods of traditional agriculture, and it can also further reduce problems such as leakage and emissions and their impact of climate change [11].

Since the role of smart systems in sustainable agriculture is increasing day by day, many technological methods have been used and recommended in recent years. Smart farming optimizes complex farming systems by applying new and modern technologies in agriculture. It aims to produce and collect more quality crops with less investment, irrigation, and human labor. In general, plant growth and harvest processes are critical issues in smart farming. Therefore, intelligent mechanism models will be very useful in solving identified problems and achieving specified goals. However, an approach that covers the whole process, not a single or specific goal(s), is important.

2. Smart and Mechanized Agricultural Application

In traditional agriculture, farmers cannot prepare the soil properly because they only use hoes after burning the bush and clearing the field. In addition, they cannot get fertile results as they can only scratch the earth and mix the ashes into the soil [12]. The burning method damages the soil, and as a result, erosion is exacerbated as this burnt soil is left bare. Furthermore, roots cannot go deep enough to absorb water and mineral salts from the soil, and thus water (the most important and critical resource) is used inefficiently. The soil can become very poor in a short time due to the usual techniques applied incorrectly and inefficiently, and to solve this problem (i.e., the soil becomes fertile again), the field must be left fallow for two or three years [13]. Since the farmers cannot stay idle during this period, they move to another field, which is called alternating cultivation. As a result, large-scale lands will not be used, and bountiful crops will not be produced. Mechanism systems blended with new technologies can be the solution to these problems. On the other hand, it is also very important to harvest the crops efficiently, on time, with the maximum amount and quality and least use of energy and resources. However, traditional methods consume resources excessively, the rate of poorer-quality crops is higher, the profit rates are not fully maximized, and most importantly, they cannot offer sustainability [14]. These problems can be resolved with the transition to modern agriculture. In this regard, the IoT and mobile robots provide great contributions. In the solution to these complex situations, software techniques and methods are needed together with new technologies. According to this, artificial-intelligence-based smart methods are becoming more important day by day. In solving this type of complex problem, learning or heuristic-based solutions may be especially useful—we should not forget that some problems in this area may not have a deterministic solution. Finally, taking into account increasing human population and food demand, these problems will have dire consequences. For the reasons stated, it can be concluded that intelligent agriculture is an essential requirement.

The IoT and similar technologies such as wireless sensor networks (WSNs) [15], which have become popular in recent years, are used to meet the needs in this field. The IoT in agriculture means using sensors and other devices to turn every element and action involved in farming into data [16]. Scientists believe that the IoT will lead the agriculture sector to agriculture 4.0 and even agriculture 5.0 in the future [17][18]. This new philosophy, data-driven agriculture, is also expressed in the literature with several different names: Agriculture 4.0, digital farming, or smart farming [19]. This smart farming can be combined with the precision agriculture concept in data management, leading to more accurate and efficient results [20]. In traditional methods, farmers had to go to the farmland and check the condition of their crops, and they would decide based on their experience whether it was time to harvest. New technologies such as the IoT are very useful in solving these problems, and more, to achieve greater efficiency, sustainability, and availability rates. Additionally, in traditional methods, the experienced farmer had a higher success rate, so younger farmers had a lower chance at succeeding. However, thanks to these new technologies, this problem can now be eliminated. On the other hand, savvy farmers can also adapt to new methods. IoT technologies are predicted to play a major role in the generation of large amounts of valuable information in all types of agriculture and the advancement of this sector [21]. In addition, the IoT is thought to be a potential solution to increasing agricultural productivity by 70% by 2050 [22]. In [23], the authors designed an IoT-based system to monitor air and soil parameters and develop mobile and web-based applications. They tried to monitor crop and yield forecasts in real time. In [24], the authors focused on farm management information systems to automate data acquisition and processing, monitoring, planning, decision-making, documenting, and managing farm operations. For this, they proposed architecture and implemented it in two different regions in Turkey. In another proposed example to monitor various components of the farmland with an IoT-based mechanism, an agro-meteorological system was developed using an Arduino [25]. Another study based on sensors, IoT, ZigBee, and Arduino focused on rural agriculture [26]. The authors tried to guide farmers in estimating crop suitability and other relevant factors by using various types of sensors. Another study explored how accurate analysis of agro-meteorological and weather parameters can help farmers improve crop production [27]. However, their proposed system is not portable, and may only be suitable for small-scale farms. Other IoT-based studies in modern agriculture in recent years have also been explored in [28][29][30].

Along with the IoT, the widespread use of autonomous robots such as UAVs increases productivity in agriculture. Recently, studies related to this subject have accelerated [31][32][33][34][35]. One of several studies in the literature is presented in [36]. The authors used UAVs to detect possible drainage pipes. Often, farmers need to repair or construct drain lines to efficiently remove water from the soil. Therefore, in this study, they wanted to decrease resource consumption and increase productivity in agriculture by focusing on this issue. In [37], the authors offered a combined application of UAVs and unmanned ground vehicles (UGVs) to monitor and manage crops. The authors proposed a system that can periodically monitor the condition of crops, capture multiple images of them, and determine the state of the crops. In addition to many UAV-based studies and products, recently the concepts of the IoT and autonomous robots have begun to be presented together. In this way, the data detected by the UAVs reaches the place where it needs to be sent instantly, the necessary actions can be taken on this data, and it can quickly provide a decision mechanism to the farmer or other technological devices. For example, in [33], the authors present a farm-monitoring system using UAV, IoT, and Long-Range Wide Area Network (LoRAWAN) technologies for efficient resource management and data delivery. In this study, they were monitoring water quality.

In general, most of the studies were aimed at increasing efficiency in the field with technological approaches. It is also very important to efficiently analyze and evaluate the data generated from new technologies such as IoT and UAV using recent technologies such as WebGIS [38]. At the same time, people may sometimes encounter complex situations for a service expected to be provided in smart agriculture. These problems become more difficult to solve as the dimension and number of uncertain parameters increase. Metaheuristic algorithms can be an appropriate mechanism for solving similar problems. Indeed, in recent years in the literature, metaheuristic-based approaches have been proposed for different purposes related to agriculture [39]. For example, in [40], three local search metaheuristic algorithms, which were simulated by annealing and Tabu search references, were used to calculate annual crop planning with a new irrigation mechanism. The objective function of this study was to maximize the gross benefits associated with the allocation of crops. The authors claim that the Tabu search method gave the best results in comparisons. In [41], an evolutionary algorithm was used for a complex strategic land-use problem based on the management of a farming system. This study pursued a multi-purpose strategy that fulfilled spatial constraints in the 50-year planning management of the farm. Although the study is comprehensive, the metaheuristic method used and proposed may not be a very high-performing and efficient solution. In [42], a bi-objective optimization model was proposed that minimizes cost and maximizes geographic diversity. In the test of the proposed method, a case was considered that showed new types of relationships in the food logistics chain. Although the proposed mechanism is interesting, the number of parameters it deals with is not complex enough. In [43], the authors introduced a smart-engine-based decision system focusing on the type of crop, time/month of harvest, type of plant required for the crop, type of harvest, and authorized rental budget. According to the results from this system, the best way to rent and share agricultural equipment was provided. The other metaheuristic-based method focused on economic crop planning at the tactical level or agricultural policy planning at the national level [44]. The supposed crop products could be for home consumption, export (cash crops), or to feed milk cows. The proposed method focused on optimal farm reconstructions that met four objectives (maximize profit and balance of soil structure, and minimize the soil nitrogen and human labor), and a set of stringent constraints. In [45], the authors tried to optimize the deployment of their sensor nodes to best monitor potato and wheat crops. In this regard, they proposed a Genetic Algorithm-based method. Other studies based on metaheuristic algorithms have been presented in the literature in the last few years [46][47][48].

In summary, many studies have been carried out in the field of smart and sustainable agriculture, which has become a trend in recent years. Some of these studies, along with their characteristics, are summarized in **Table 1**. These content focuses on optimal solutions from cultivation to harvesting benefiting from the IoT, autonomous robots, and a metaheuristic approach in three stages.

Table 1. Characterization of current studies in the literature.

Study	Approach, Technique	Task and Goals
[31]	GIS system	Monitoring process based on map analysis and reduced data
[23]	IoT and autonomous robot	Monitoring process and yield forecasts by IoT devices and mobile/web app
[24]	IoT	Process management based on a farm management information system and architecture
[26]	IoT	Product management based on data analysis
[36]	Single autonomous robot	Monitoring process based on efficient water usage, controlling amounts of phosphate (PO4) and nitrate (N03), and detecting drainage pipes

Study	Approach, Technique	Task and Goals
[37] [49]	Single autonomous robot	Monitoring process based on monitoring vegetation state
[32]	Multi autonomous robots	Monitoring process based on providing a multiple UAV system for aerial imaging
[33]	Single autonomous robot, metaheuristic	Spraying process based on spraying fruits and trees
[34]	Multi autonomous robots	Spraying process based on path-planning algorithm
[42]	Metaheuristic	Food logistics chain and crop planning based on minimizing cost and maximizing geographic diversity
[44]	Metaheuristic	Convenient and efficient planting and cultivation
[39]	Metaheuristic	Annual crop planning
[43]	Metaheuristic	Rent and share agricultural equipment based on a smart-engine-based decision system
[45]	Metaheuristic and IoT	Best planting model based on optimal deployment
[48]	Metaheuristic	Optimal plant

References

1. Sylvester, G. E-Agriculture in Action: Drones for Agriculture; Food and Agriculture Organization of the United Nations and International Telecommunication Union: Bangkok, Thailand, 2018; pp. 11–22.

2. Kiani, F.; Seyyedabbasi, A.; Nematzadeh, S.; Candan, F.; Çevik, T.; Anka, F.A.; Randazzo, G.; Lanza, S.; Muzirafuti, A. Adaptive Metaheuristic-Based Methods for Autonomous Robot Path Planning: Sustainable Agricultural Applications. Appl. Sci. 2022, 12, 943.

3. Quy, V.K.; Hau, N.V.; Anh, D.V.; Quy, N.M.; Ban, N.T.; Lanza, S.; Randazzo, G.; Muzirafuti, A. IoT-Enabled Smart Agriculture: Architecture, Applications, and Challenges. Appl. Sci. 2022, 12, 3396.

4. United Nations Environment Programme. “Sustainability”. Available online: https://www.unep.org/about-un-environment/sustainability (accessed on 29 September 2021).

5. Muzirafuti, A.; Cascio, M.; Lanza, S. UAV Photogrammetry-based Mapping the Pocket Beach of Isola Bella, Taormina (Northeastern Sicily). In Proceedings of the 2021 International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea), Reggio Calabria, Italy, 4–6 October 2021; pp. 418–422.

6. Wolfert, S.; Ge, L.; Verdouw, C.; Bogaardt, M.-J. Big data in smart farming a review. Agric. Syst. 2017, 153, 69–80.

7. Kiani, F.; Seyyedabbasi, A. Wireless Sensor Network and Internet of Things in Precision Agriculture. Int. J. Adv. Comput. Sci. Appl. 2018, 9, 99–103.
8. Saiz-Rubio, V.; Rovira-Más, F. From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management. Agronomy 2020, 10, 207.
9. Kiani, F.; Seyyedabbasi, A.; Nematzadeh, S. Improving the performance of hierarchical wireless sensor networks using the metaheuristic algorithms: Efficient cluster head selection. Sens. Rev. 2021, 41, 368–381.
10. Boursianis, A.D.; Papadopoulou, M.S.; Diamantoulakis, P.; Liopa-Tsakalidi, A.; Barouchas, P.; Salahas, G.; Karagiannidis, G.; Wan, S.; Goudos, S.K. Internet of Things (IoT) and Agricultural Unmanned Aerial Vehicles (UAVs) in smart farming: A comprehensive review. Internet Things 2020, 18, 100187.
11. Wong, S. Decentralised, Off-Grid Solar Pump Irrigation Systems in Developing Countries-Are They Pro-poor, Pro-environment and Pro-women? In Climate Change-Resilient Agriculture and Agroforestry; Springer: Cham, Switzerland, 2019; pp. 367–382.
12. Singh, R.; Singh, G.S. Traditional agriculture: A climate-smart approach for sustainable food production. Energy Ecol. Environ. 2017, 2, 296–316.
13. Goldstein, M.; Christopher, U. The Profits of Power: Land Rights and Agricultural Investment in Ghana. J. Political Econ. 2008, 116, 981–1022.
14. Karikaya, A. Smart Farming-Precision Agriculture Technologies and Practices. J. Sci. Perspect. 2020, 4, 123–136.
15. Kiani, F. A novel channel allocation method for time synchronization in wireless sensor networks. Int. J. Numer. Model. Electron. Netw. Devices Fields 2016, 29, 805–816.
16. Radoglou-Grammatikis, P.; Sarigiannidis, P.; Lagkas, T.; Moscholios, I. A compilation of UAV applications for precision agriculture. Comput. Netw. 2020, 172, 107148.
17. Evan, D.; Fraser, G.; Campbell, M. Agriculture 5.0: Reconciling Production with Planetary Health. One Earth 2019, 1, 278–280.
18. Araújo, S.O.; Peres, R.S.; Barata, J.; Lidon, F.; Ramalho, J.C. Characterising the Agriculture 4.0 Landscape—Emerging Trends, Challenges and Opportunities. Agronomy 2021, 11, 667.
19. CEMA. Digital Farming: What Does It Really Mean? Available online: http://www.cema-agri.org/publication/digital-farming-what-does-it-really-mean (accessed on 21 September 2021).
20. Tzounis, A.; Katsoulas, N.; Bartzanas, T.; Kittas, C. Internet of Things in agriculture, recent advances and future challenges. Biosyst. Eng. 2017, 164, 31–48.

21. Sarni, W.; Mariani, J.; Kaji, J. From Dirt to Data: The Second Green Revolution and IoT. Deloitte Insights. Available online: https://www2.deloitte.com/insights/us/en/deloitte-review/issue-18/second-greenrevolution-and-internet-of-things.html#endnote-sup-9 (accessed on 22 September 2021).
22. Sandeep, V.; Amol, D.; Vibhute, D.; Karbhari, V.; Suresh, K.; Mehrotra, C. An innovative IoT based system for precision farming. Comput. Electron. Agric. 2021, 187, 106291.
23. Köksal, Ö.; Tekinerdogan, B. Architecture design approach for IoT-based farm management information systems. Precis. Agric. 2019, 20, 926–958.
24. Jangam, A.R.; Kale, K.V.; Gaikwad, S.; Vibhute, A.D. Design and development of IoT based system for retrieval of agrometeorological parameters. In Proceedings of the International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE), Bhubaneswar, India, 27–28 July 2018; pp. 804–809.
25. Robles, J.R.; Martin, Á.; Martin, S.; Ruipérez-Valiente, J.; Castro, M. Autonomous sensor network for rural agriculture environments, low cost, and energy self-charge. Sustainability 2020, 12, 5913.
26. Sawant, S.; Durbha, S.S.; Jagarlapudi, A. Interoperable agro-meteorological observation and analysis platform for precision agriculture: A case study in citrus crop water requirement estimation. Comput. Electron. Agric. 2017, 138, 175–187.
27. Ayaz, M.; Ammad-Uddin, M.; Sharif, Z.; Mansour, A.; Aggoune, E.M. Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk. IEEE Access 2019, 7, 129551–129583.
28. Nabi, F.; Jamwal, S.; Padmanbh, K. Wireless sensor network in precision farming for forecasting and monitoring of apple disease: A survey. Int. J. Inform. Technol. 2020, 14, 769–780.
29. Vitali, G.; Francia, M.; Golfarelli, M.; Canavari, M. Crop Management with the IoT: An Interdisciplinary Survey. Agronomy 2021, 11, 181.
30. Tayari, E.; Jamshid, A.R.; Goodarzi, H.R. Role of GPS and GIS in precision agriculture. J. Scient. Res. Dev. 2015, 2, 157–162.
31. Del Cerro, J.; Cruz Ulloa, C.; Barrientos, A.; de León Rivas, J. Unmanned Aerial Vehicles in Agriculture: A Survey. Agronomy 2021, 11, 203.
32. Dai, B.; He, Y.; Gu, F.; Yang, L.; Han, J.; Xu, W. A vision-based autonomous aerial spray system for precision agriculture. In Proceedings of the 2017 IEEE International Conference on Robotics and Biomimetics (ROBIO), Macau, China, 5–8 December 2017; pp. 507–513.
33. Behjati, M.; Mohd Noh, A.B.; Alobaidy, H.A.H.; Zulkifley, M.A.; Nordin, R.; Abdullah, N.F. LoRa Communications as an Enabler for Internet of Drones towards Large-Scale Livestock Monitoring in Rural Farms. Sensors 2021, 21, 5044.

34. Li, X.; Zhao, Y.; Zhang, J.; Dong, Y. A hybrid PSO algorithm based flight path optimization for multiple agricultural uavs. In Proceedings of the 2016 IEEE 28th International Conference on Tools with Artificial Intelligence (ICTAI), San Jose, CA, USA, 6–8 November 2016; pp. 691–697.
35. Allred, B.; Eash, N.; Freeland, R.; Martinez, L.; Wishart, D. Effective and efficient agricultural drainage pipe mapping with uas thermal infrared imagery: A case study. Agric. Water Manag. 2018, 197, 132–137.
36. Vasudevan, A.; Kumar, D.A.; Bhuvaneswari, N.S. Precision farming using unmanned aerial and ground vehicles. In Proceedings of the 2016 IEEE Technological Innovations in ICT for Agriculture and Rural Development (TIAR), Chennai, India, 15–16 July 2016; pp. 146–150.
37. Memmah, M.M.; Lescourret, F.; Yao, X.; Lavigne, C. Metaheuristics for agricultural land use optimization. A review. Agron. Sustain. Dev. 2015, 35, 975–998.
38. Randazzo, G.; Italiano, F.; Micallef, A.; Tomasello, A.; Cassetti, F.P.; Zammit, A.; D’Amico, S.; Saliba, O.; Cascio, M.; Cavallaro, F.; et al. WebGIS Implementation for Dynamic Mapping and Visualization of Coastal Geospatial Data: A Case Study of BESS Project. Appl. Sci. 2021, 11, 8233.
39. Chetty, S.; Adewumi, A.O. Three new stochastic local search metaheuristics for the annual crop planning problem based on a new irrigation scheme. J. Appl. Math. 2013, 2013, 158538.
40. Chikumbo, O.; Goodman, E.; Deb, K. Approximating a multidimensional Pareto front for a land use management problem: A modified MOEA with an epigenetic silencing metaphor. In Proceedings of the Evolutionary Computation (CEC), Brisbane, Australia, 10–15 June 2012; pp. 1–9.
41. Adenso-Díaz, B.; Villa, G. Crop Planning in Synchronized Crop-Demand Scenarios: A Biobjective Optimization Formulation. Horticulturae 2021, 7, 347.
42. Rakhra, M.; Singh, R.; Lohani, T.; Shabaz, M. Metaheuristic and Machine Learning-Based Smart Engine for Renting and Sharing of Agriculture Equipment. Math. Probl. Eng. 2021, 2021, 5561065.
43. Pal, P.; Sharma, R.P.; Tripathi, S.; Kumar, C.; Ramesh, D. Genetic algorithm optimized node deployment in IEEE 802.15.4 potato and wheat crop monitoring infrastructure. Sci. Rep. 2021, 11, 8231.
44. Chetty, S.; Adewumi, A.O. Comparison Study of Swarm Intelligence Techniques for the Annual Crop Planning Problem. IEEE Trans. Evol. Comput. 2014, 18, 258–268.
45. Dwivedi, A.; Jha, A.; Prajapati, D.; Sreenu, N.; Pratap, S. Meta-heuristic algorithms for solving the sustainable agro-food grain supply chain network design problem. Mod. Supply Chain. Res. Appl. 2020, 2, 161–177.

46. Sabzi, S.; Abbaspour-Gilandeh, Y.; García-Mateos, G. A fast and accurate expert system for weed identification in potato crops using metaheuristic algorithms. Comput. Ind. 2018, 98, 80–89.
47. Khan, M.S.; Anwar ul Hassan, C.H.; Sadiq, H.A.; Ali, I.; Rauf, A.; Javaid, N. A New Meta-heuristic Optimization Algorithm Inspired from Strawberry Plant for Demand Side Management in Smart Grid. In International Conference on Intelligent Networking and Collaborative Systems; Springer: Cham, Switzerland, 2018; pp. 143–154.
48. Jiang, S.; Zhang, H.; Cong, W.; Liang, Z.; Ren, Q.; Wang, C.; Zhang, F.; Jiao, X. Multi-Objective Optimization of Smallholder Apple Production: Lessons from the Bohai Bay Region. Sustainability 2020, 12, 6496.
49. Sharma, V.; Tripathi, A.K. A systematic review of meta-heuristic algorithms in IoT based application. Array 2022, 14, 1–8.