A Framework for Real-Time Crop Monitoring and Yield Optimisation: Improving Precision Agriculture with IoT-Driven Sensor Networks and Data Analytics

Ammar H. Shnain[1*], *G.* Mohammed[2], and *Yalla Jeevan Nagendra* Kumar[3]

[1]Department of computers Techniques engineering, College of technical engineering, The Islamic University of Najaf, Iraq
[1]The Islamic University of Al Diwaniyah, Al Diwaniyah, Iraq and The Islamic University of Babylon, Babylon, Iraq
[2]Ahl Al Bayt University, Karbala, Iraq
[3]Department of Information Technology, Gokaraju Rangaraju Institute of Engineering and Technology, JNTUH, Bachupally, Hyderabad, Telangana, India

Abstract. Using smart data analytics and IoT-driven sensor networks to enhance precision agriculture, the paper provides a whole framework for real-time Crop Monitoring and yield optimization. Using IoT-Driven Sensor Networks (CM-IoT-SN), Crop Monitoring aims to provide farmers practical data for maximizing yields and improving crop condition. Many times, existing precision agricultural technologies suffer from flaws such as poor data granularity, delayed feedback, and the difficulty to provide real-time monitoring across large agricultural fields. These weaknesses lower crop productivity and lead to less than perfect decision-making. To solve these challenges, CM-IoT-SN combines a network of IoT-enabled sensors continuously monitoring key environmental factors such as soil moisture, temperature, and nutrient levels. Advanced algorithms then utilize the real-time data acquired to provide farmers expected insights and quick advise.CM-IoT-SN's adoption across many test locations has proved its effectiveness in producing superior decision-making in crop management by means of exact, real-time monitoring and predictive analytics. Results reveal that this approach not only increases crop productivity however additionally reduces resource waste, therefore providing a sustainable substitute for modern agriculture.

1 Introduction

These days modern farmers have also to cope with the necessity of long term sustainability and that of higher productivity through reduced use of the resources [1]. These issues have [2] resulted in Precision farming being an important solution to these issues. With conventional agriculture, data is collected and processed manually leading to a heavy labor

* Corresponding author: ammar.hameed.it@gmail.com

as well as prone to errors. Also, this procedure is lengthy, which limits the reaction of farmers' capability to perform well and intelligently as there is no real time monitoring and feedback technologies [3].

The three main limitations to farming with these sensors are surmounted by combining the technology with the internet of things (IoT). True real time data from these types of environmental factors like soil moisture, temperature and fertilizer levels can change the way farmers live for the better through the use of IoT sensor networks. Such an advancement can bring a monumental change to the agricultural industry [4].

The motivation of this study is to equip the platform with a comprehensive mechanism for real time crop monitoring and to optimize agricultural production. The proposed system, Crop Monitoring Internet of Things Sensor Network (CM-IoT-SN) attempts to provide actionable insights that will enable farmers to improve their crop management [6]. The primary intention of CM-IoT-SN is to improve agricultural decision making confronting the data inaccuracies and delayed respond experienced from the current precision farming technologies [7].

Through its use of multiple test sites, this framework has proven how it can improve agricultural yield while waste limiting to resources. As a result, it helps improve these farming practices. This paper analyzes the design, implementation and implication of the CM-IoT-SN framework, which can provide transformation in the modern agriculture.

1.1 Contribution of this paper

Create infrastructure using IoT-enabled sensor networks to provide finely grained, real-time data on important environmental parameters. This will improve the accuracy of crop monitoring. This will allow more accurately monitoring crops.

Data analytics helps one to enhance agricultural output on the second level. This demands the use of advanced algorithms with real-time data analysis to provide pragmatic knowledge. This helps farmers to make reasonable decisions that maximize agricultural production and reduce resource use.

Additionally, is to promote sustainable agriculture by demonstrating via timely supply of pertinent data how the CM-IoT-SN architecture may assist to reduce fertilizer and water waste. Using sustainable agriculture can help farmers to live simpler lives.

The upcoming section is as follows: section 2 deliberates the related works, section 3 examines the proposed methodology, section 4 describes the results and discussion and section 5 concludes the overall paperwork.

2 Related work

Modern data analytics linked with the IoT is changing agricultural methods as it permits exact crop monitoring and management just in time. This is the reason the sector of agriculture is changing. Improving agricultural management is the major goal of it, which will be executed especially with regard for onion crops. Farmers might learn more about the status and development patterns of their crops via sensors and cloud data processing. This information might enable them to raise better quality crops. Moreover, the approach uses machine learning to foresee and make judgments, therefore improving resource economy and enabling environmentally friendly business operations.

Being able to monitor far distances gives greater freedom and swift intervention power. Environmental monitoring utilizing IoT devices may help farmers better prepare, understand the consequences of climate change, and use sustainable practices. Monitoring variables such air quality, water quality, and weather patterns can help make wiser judgments. By monitoring shipments and storage conditions, IoT sensors and tracking devices help to maximize the agricultural supply chain. This helps to make the food of superior quality and streamlines the supply chain. Combining data from the IoT with algorithms for AI and machine learning, decision support systems provide farmers insightful analysis and recommendations [8]. Among the tools the IoT is enhancing farm security with are cameras, motion detectors, and access control systems. Real-time alerts let one avoid theft, trespassing, or vandalism by enabling quick responses to suspicious acts. By encrypting data and using safe communication techniques, one lowers the possibility of unauthorized access while safeguarding private information of farmers. Farms may protect their assets and promote the general usage of IoT and the security measures it involves for agricultural benefit in the future.

Hereby provide a strategy using cloud-based software and IoT sensors for bettering onion crop management. Among the IoT sensors utilized to compile vital data on the onion farms are soil moisture, temperature, humidity, and drones. Reduced bandwidth usage and latency allows optional edge computing devices to provide real-time data processing. The acquired data is combined and securely kept on a cloud platform so that advanced data analysis and insights are enabled. By use of machine learning algorithms, the cloud platform might provide valuable insights on the health, development path, and patterns of growth of the onion [9]. Automated alerts and notifications help farmers of any deviations from optimum conditions, including as moisture levels or insect infestations by means of timely response. The predictive features of the system enable accurate fertilizer control and irrigation, therefore optimizing the use of resources and improving crop health. A gold mine of information, accumulated historical data may help one identify trends and project future development for following planting seasons. As regards data security and privacy all through the process, encrypted data transport and storage is in place to protect private information belonging to farmers. Using cloud computing and the IoT will let one monitor the development of crops more easily than otherwise. The proposed approach increases productivity, supports environmentally friendly agricultural methods, and gives farmers helpful knowledge.

It intends to effectively manage agricultural irrigation by creating suitable valve control orders using the capabilities of the IoT and a Decision Support System (DSS) based on Big Data [10]. Three alternative prediction methods a Deep Neural Network (DNN), a Random Forest (RF), and a Resilient Back-Propagation Neural Network model are tested for one hour ahead of time soil Moisture Content (MC) using six different sensors. Data in real-time is gathered using the field-tested advised method for IoT node deployment. Using an IoT-based DSS architecture that compiles 17 soil and ambient properties, one hour in advance one might estimate change in soil MC. To assess site-and zone-specific irrigation management strategies, the test site uses a weather-dependent model based on fuzzy logic.

The proposed initiative aims to enhance onion crop management, hence it implies an IoT-based infrastructure. Cloud computing and sensors help the system to do real-time monitoring and predictive analytics. The system improves sustainability as well as production by way of precise irrigation, fertilizer control, and timely interventions. Furthermore much enhanced are lifespan and production. Farmers might acquire relevant insights and apply strict security requirements to gently secure their data by applying current data analysis on a user-friendly platform. The design is a wonderful example of how the Internet of Things may improve currently in use traditional farming methods.

3 Proposed method

Modern technology such as robotics, artificial intelligence (AI), big data analytics and Internet of Things (IoT) has been redefining precision agriculture. This technology makes it possible to obtain more information and have more efficient, data driven decisions in a way that's able to increase agricultural productivity.

The system integrating cloud computing and data driven decision making with the aims to optimize farming operation is shown in Figure 1. The system features the ability to use real time data from IoT sensors and do AI based analytics on top of that, to help in crop monitoring and resource allocation to in turn give the best Agricultural outcomes.

Figure 2 is a paradigm that shows how the AI can totally reinvent agricultural tactics, for instance, through predictive modeling and automation. This model shows how AI algorithms can tackle environmental and soil conditions, predict crop health and do the automatization of critical farming processes in reducing waste of resources increasing the productivity.

The incorporation of these models contributes toward a more comprehensive understanding of the process of shifting from farming based on resource and technologically intensive, sustainable and environmentally efficient concepts. These models have mathematical formulations, which offer scientific basis to the proposed framework. Nevertheless, an even more elaborate account of the variables and their responsibility in the system will make the analysis more succinct, helping the reader draw inferences about real life applications of the variables.

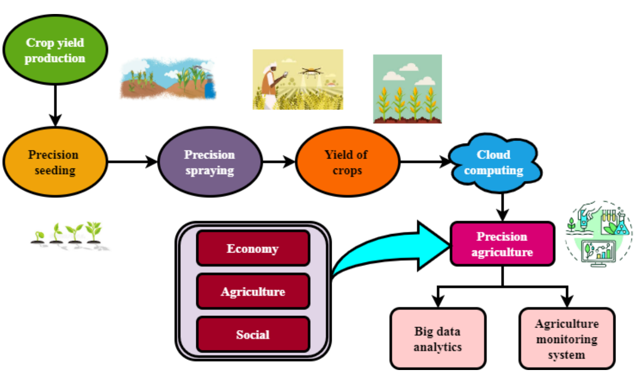

Fig.1. Integrated Framework for Precision Agriculture: Enhancing Crop Yield with IoT

Including the IoT, cloud computing, and big data analytics, this interactive diagram provides a foundation for precision farming. This method tries to maximize agricultural productivity as shown in figure 1. Exactlying seed planting and chemical spray application marks first steps in a process that at last produces more agricultural yield. Informed decision-making depends on the ability to acquire and assess data in real time; cloud computing helps to supply this capability, therefore aiding precision agriculture. Furthermore underlined in the framework is the larger impact of these technologies on social, economic, and agricultural domains. This impact aids in the development financially viable and environmentally sustainable farming methods.

$$\frac{Et}{f(g-u)} = dfm^{-\partial_2 U_2} * Q(b-4) - \forall_d * F(G) \ (1)$$

Et represents the overall efficiency of crop surveillance in equation 1, and $f(g-u)$ is the function that quantifies the difference between the observed and ideal circumstances. The $dfm^{-\partial_2 U_2}$ represents the decrease in data accuracy with time, whereas $Q(b-4)$ denotes the adjustment in quality depending on environmental factors. Finally, the equation $\forall_d * F(G)$ denotes the efficiency dependence of analysis of crop productivity.

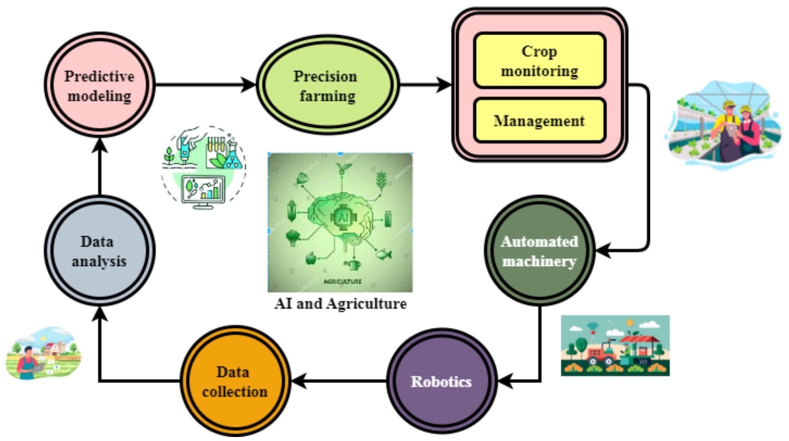

Fig. 2. AI-Driven Precision Agriculture: Enhancing Crop Management through Automation and Data Analytics

Here is a notion of a precision agriculture framework powered by AI as shown in figure 2. Among the many technologies included in the relevant framework are not limited here predictive modeling, data analysis, and robotics. Data collecting begins the process of acquiring the best possible results by means of precision farming methods; it then moves on with the construction of prediction models and data analysis. Direct effects of the usage of robots and automated technology in crop monitoring and management include better agricultural operations. It stress the potential of AI in agriculture and explain how it may transform conventional agricultural practices by raising general production, improving precision, and reducing labor demand.

$$F^{g-hp} = T - v_2 U(p+Qr) - \partial_v(1-Pt) \ (2)$$

The agricultural yield function, taking environmental and system characteristics into account, is represented by the equation 2, F^{g-hp}. In this context, T refers to the overall potential yield, $v_2 U(p+Qr)$ represents the influence of environmental factors and the truthfulness of sensor data on yield, and $\partial_v(1-Pt)$ represents the reduction in yield efficient caused by resource limits or operational problems on analysis of reduces resource waste.

Modern farming is mixing AI, the IoT, and automation as seen by both of these diagrams. Both approaches pay close focus on how AI might revolutionize automation and agricultural management. By use of precision agriculture methods and cloud computing, crop output will be raised, thus directing the first approach. different models provide a comprehensive view of the way agriculture is heading by addressing how different technologies effect efficiency, sustainability, and production.

4 Result and discussion

Driven by the IoT, data analytics' integration with sensor networks is ushering a new era of precision agriculture flowering in accuracy. This sort of technology gives farmers useful insights which may use to optimize resources and raise agricultural output. By means of real-time environmental data monitoring including temperature and soil moisture they enable to The paper presents a comprehensive framework accessible here: CM-IoT-SN. More environmentally friendly farming methods are part of the expected outcomes of this effort to increase crop monitoring and production optimization.

Table 1. Comparison of Existing methods and Proposed method

Parameter	Existing Method (%)	Proposed CM-IoT-SN Method (%)
Crop Productivity Increase	78	96
Water Usage Efficiency	65	92
Fertilizer Efficiency	60	90
Pesticide Optimization	55	88
Resource Waste Reduction	40	85
Environmental Impact Reduction	50	87

4.1 Analysis of crop productivity

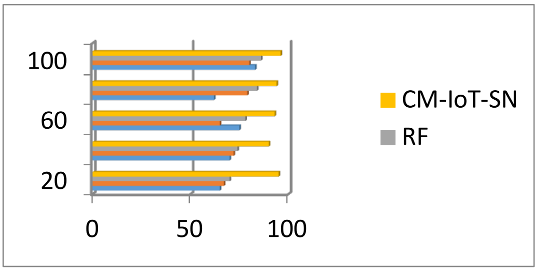

Fig. 3. Crop productivity

The highly accurate, real-time environmental conditions provided by the CM-IoT-SN gadget greatly increase agricultural productivity which is shown in figure 3. This information helps one to make focused changes to irrigation, fertilizer, and pest management, therefore producing an environment fit for growth. The system's overall comprehensive analytics help one to foresee issues and use proactive management techniques. This instantly creates ideal conditions for crop development; furthermore, the superior quality and larger yields they provide serve to boost agricultural production. Crop productivity is gradually increased using this proposed method by the ratio of 96%.

4.2 Analysis of reduces resource waste

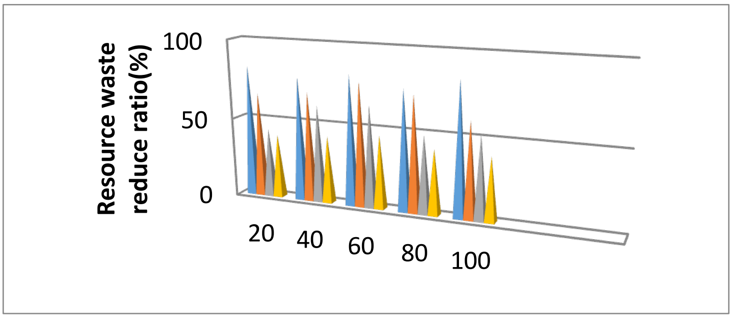

Fig. 4. Reduce Resource waste (%)

CM-IoT-SN rather effectively decreases resource waste by using targeted, data-driven management. This is made possible most effectively by most efficient use of inputs including water and fertilizers which is described in figure 4. Real-time monitoring ensures that resources are only used precisely and only when required, therefore preventing misuse. It now know, thus, that resources won't go to waste. Although agricultural practices harm the environment, this targeted approach helps to reduce waste, control expenditure, and thus mitigate that impact. This therefore encourages a farming approach more sustainable with improved long-term resource economy. Using this proposed method resource waste is analysed and reduce the value compared to the existing method.

By means of data analytics and sensor networks connected to the Internet of Things, the CM-IoT-SN system lowers resource waste, therefore improving agricultural productivity. Thus, more usually utilized sustainable agriculture techniques help to lower resource waste and increase food output. Exact monitoring this technology and real-time decision-making assist to make this feasible.

5 Conclusion

Combining robust data analytics with IoT-powered sensor networks, the CM-IoT-SN architecture improves precision agriculture for the modern society. This method lets can significantly cut resource waste and simultaneously increase agricultural productivity. This is made feasible by the availability of very accurate, current data on significant environmental factors. After CM-IoT-SN was installed at many test sites, it was found that improving farmers' decision-making and inspiring them to engage in environmentally responsible farming works. Adoption of this paradigm allows farmers maximize resource use and crop management, therefore generating an agricultural business that is both environmentally benign and efficient. This approach will enable all the issues current agricultural businesses deal with to be fully resolved.

Incorporating more complex machine learning algorithms and raising the capacity of the sensor network will enable the CM-IoT-SN to monitor a wider variety of crop varieties over a larger number of agricultural regions in future iterations. Then the design will be better suited to meet current needs. Further initiatives will be focused on improving data security and looking at blockchain technology' prospective application to provide agriculture sector safe data management and improved traceability. These will be done in line with currently in use guidelines meant to improve data security.

Reference

1 U. Avalekar, D.J. Patil, D.S. Patil, P. Khot, P. Prathapan, Optimizing Agricultural Efficiency: A Fusion Of IoT, AI, Cloud Computing, And Wireless Sensor Network. Prof.(Dr.) Kesava (2024). https://doi.org/10.2139/ssrn.4789232
2 R.K. Singh, R. Berkvens, M. Weyn, AgriFusion: An architecture for IoT and emerging technologies based on a precision agriculture survey. IEEE Access 9, 136253-136283 (2021). https://doi.org/10.1109/ACCESS.2021.3117597
3 M. Champness, C. Ballester-Lurbe, R. Filev-Maia, J. Hornbuckle, Smart sensing and automated irrigation for sustainable rice systems: A state of the art review. Adv. Agron. 177, 259-285 (2023). https://doi.org/10.1016/bs.agron.2022.11.002
4 H.K. Sharma, Intelligent IoT for Precision Agriculture, in Computational Intelligence for Wireless Sensor Networks (Chapman and Hall/CRC, 2022), pp. 77-92. https://doi.org/10.1201/9781003102397-5
5 M.N. Mowla, N. Mowla, A.S. Shah, K. Rabie, T. Shongwe, Internet of things and wireless sensor networks for smart agriculture applications-a survey. IEEE Access (2023). https://doi.org/10.1109/ACCESS.2023.3340407
6 D. Huo, A.W. Malik, S.D. Ravana, A.U. Rahman, I. Ahmedy, Mapping smart farming: Addressing agricultural challenges in data-driven era. Renew. Sust. Energ. Rev. 189, 113858 (2024). https://doi.org/10.1016/j.rser.2023.113858
7 C. Pero, S. Bakshi, M. Nappi, G. Tortora, IoT-Driven Machine Learning for Precision Viticulture Optimization. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. (2023). https://doi.org/10.1109/JSTARS.2023.3343458
8 C. Liang, T. Shah, IoT in agriculture: The future of precision monitoring and data-driven farming. Eigenpub Rev. Sci. Technol. 7(1), 85-104 (2023). https://doi.org/10.1007/978-981-97-5878-4_11
9 A. Khan, M. Hassan, A.K. Shahriyar, Optimizing onion crop management: a smart agriculture framework with IoT sensors and cloud technology. Appl. Res. Artif. Intell. Cloud Comput. 6(1), 49-67 (2023)
10 B. Keswani, A.G. Mohapatra, P. Keswani, A. Khanna, D. Gupta, J. Rodrigues, Improving weather dependent zone specific irrigation control scheme in IoT and big data enabled self driven precision agriculture mechanism. Enterp. Inf. Syst. 14(9-10), 1494-1515 (2020). https://doi.org/10.1080/17517575.2020.1713406