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A Comprehensive Analysis on AI Driven Mathematical Regression Framework for Predictive Maintenance in Drone Based Crop Monitoring System

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***Abstract-** The increased use of AI (Artificial Intelligence) in precision agriculture has led to tremendous developments in predictive maintenance and crop monitoring systems, particularly by drone-based systems. This literature review aims to discuss recent developments in artificial intelligence based mathematical regression models, particularly in improving efficiency in maintenance and crop monitoring systems. The discussion in this literature review will particularly focus on recent developments in machine learning and deep learning techniques, particularly in improving efficiency in maintenance and crop monitoring systems. This literature review will also focus on recent developments in integrating Internet of Things technology, drones, sensors, and edge computing technology, particularly in improving efficiency in acquiring data in real time by applying techniques in explainable AI, hybrid learning techniques, and digital twins, particularly in improving efficiency in decision making processes in maintenance and crop monitoring systems. In addition, recent developments in applying thermal imaging technology, computer vision technology, and anomaly detection techniques will be discussed in improving efficiency in identifying faults in equipment by drones in crop monitoring systems. Sustainable and energy efficient techniques in applying AI technology will also be discussed in improving efficiency in climate resilient crop monitoring systems. Thus, this literature review aims to discuss recent developments in technology and methodology, data driven maintenance strategies in drone assisted crop monitoring systems.*

***Keywords:** Internet of Things (IoT), Drones, UAV, Artificial Intelligence (AI), Machine Learning*

I. INTRODUCTION

The rapid increase in agricultural activities due to digitalization has led to the development of precision agriculture as a significant aspect in improving agricultural activities. In this context, the development of artificial intelligence based drone monitoring systems has provided a new dimension in improving smart agricultural activities by incorporating the aspect of precision agriculture. The development of artificial intelligence based mathematical regression in predictive maintenance in drone-based crop monitoring has provided a new paradigm in improving crop monitoring activities by ensuring optimal performance in these activities. At the same time, the framework has minimized system failure in these activities, thus improving efficiency in agricultural activities. Titirmare et al. have discussed the application of artificial intelligence based predictive analytics in optimizing crop yields by using regression-based analytics in these activities[1]. Artificial intelligence has provided a new dimension in improving crop monitoring activities by analyzing large scale heterogeneous data sets in agricultural environments. The data sets analyzed in these frameworks include data sets generated on crop monitoring activities, environmental conditions, and drone monitoring activities. Kisten et al. have discussed the application of explainable artificial intelligence in predictive maintenance in smart agriculture activities, thus improving crop monitoring activities by using advanced machine learning techniques in these activities[2]. The application of machine learning has provided a new dimension in improving crop monitoring activities by identifying complex patterns in data sets in these activities. The data sets analyzed in these frameworks include data sets generated in crop monitoring activities, environmental conditions, and drone monitoring activities. The supervised machine learning algorithms have created new avenues for the improvement of crop monitoring techniques. The unsupervised machine learning algorithms have created new opportunities in the improvement of crop monitoring techniques. Goel et al. done improvement in crop monitoring techniques by applying machine learning based remote monitoring techniques using IoT based analytics[3]. The mathematical regression models play a vital role in the improvement of crop monitoring techniques, which help in developing a systematic approach in modeling the relationships between the dependent and independent variables.

Hernández Hernández et al. presented the overview of the application of AI based predictive models in crop yield estimation techniques[4]. The linear regression, polynomial regression, support vector regression, and ensemble based regression techniques are used in predicting the degradation of equipment, battery life, crop yields, and environmental parameters, etc. These techniques can be used in accurately predicting the degradation of equipment, which in turn can be used in maintaining the equipment. The deep learning techniques can be used in enhancing these techniques, which can be used in processing complex data. Shuriya discussed the deep learning based precision agriculture techniques using autonomous sensing techniques[5]. The techniques can be used in image analysis techniques, which can be used in detecting crop diseases, pests, and crop health analysis techniques by taking aerial images, etc. The RNN and LSTM techniques can be used in time series analysis techniques, which can be used in detecting trends in environmental parameters, which in turn can be used in accurately predicting the crop monitoring techniques. Drone based systems, also known as UAVs, form a part of a system where data acquisition takes place through these systems, which include high resolution camera systems, as well as other sensors such as multi spectral sensors, hyper spectral sensors, thermal imaging sensors, etc., to acquire data pertaining to crop health, soil moisture content, nutrient content, temperature changes, etc.

In the recent past, Li has examined the economic benefits associated with the use of AI based precision agriculture through the application of UAV based remote sensing technology[6]. The role of the use of the UAV, also known as drones, is significant in terms of covering the agricultural fields in an economically viable manner in which the acquisition of information is possible in real time with high spatial resolution. In terms of the use of AI based autonomous robotics and drones, Kishor et al. propose the application of the same in the context of predictive maintenance and the enhancement of the operations associated with the system[7]. In terms of predictive maintenance, the drones also keep track of the various parameters associated with the system, such as the battery life, motor efficiency, flight stability, etc. The application of Internet of Things (IoT) is also significant in terms of the enhancement of the efficiency associated with the system in which communication is possible between the systems. Kar and Chowdhury propose the application of IoT based drone based field monitoring systems in which surveillance and data collection occur[8]. The IoT sensors play an important role in terms of monitoring the system in which the connected system is useful in terms of acquiring information in real time. The connected system is also useful in terms of predictive maintenance in which real time information is required. The other important aspect related to the system is the application of the edge computing and cloud computing technologies. The first aspect of these kinds of systems is edge computing and cloud computing technologies. Such technologies are helpful in getting efficient solutions for handling complex data and complex AI models in a proper manner. Such systems are not only helpful in getting efficient solutions for handling complex data, but they are also helpful in getting a real time solution for critical situations.

Geetha & Deepika have also proposed an AI based drone assisted system for efficient pest management and yield optimization using computer vision techniques[9]. Computer vision techniques are being utilized for getting a proper understanding of the data collected through drones. Such systems are helpful in getting a proper understanding of the situations where diseases, pests, and other kinds of irregularities are happening in the fields. Guatno et al. have also explored the potential of using thermal imaging drones and color condition sensors for efficient predictive yield analysis and intelligent inventory management systems[10]. Such systems are helpful in getting a proper prediction of the yield by detecting the temperature changes which might occur because of equipment failures in the fields. Such systems are helpful in maintaining the fields effectively. Apart from these technologies, another aspect of these kinds

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of systems is getting a proper utilization of the potential of the technology called Explainable AI in order to enhance the level of transparency in these kinds of systems. Such systems are helpful in getting a proper bond of trust with the users of such systems. The newly evolving concepts of digital twin technology are also becoming popular due to the possibility of creating the virtual world of the physical world.

This is a review article, and in this article, different advanced technologies used in precision agriculture, which is known as drone assisted crop monitoring and predictive maintenance, are discussed. The advanced technology used in this article is: Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Explainable AI (XAI), Internet of Things (IoT), Drones/UAVs, Autonomous Robots, Edge Computing, Regression Models & Predictive Analytics, Digital Twin Technology, Advanced Sensors, Energy Efficient AI & Solar Powered Systems.

II. LITERATURE REVIEW

2.1 Overview of Predictive Maintenance in Drone based Crop Monitoring System:

Singh et al.[11] propose a drone assisted precision agriculture system based on a hybrid approach to machine learning. The work primarily focuses on the integration of aerial imaging and predictive analytics. The proposed framework can be utilized for predictive maintenance by identifying any changes in the performance of the drone. This can improve the sustainability of the drone assisted precision agriculture system. Ramteke et al.[12] worked on UAV assisted spraying systems based on AI assisted life cycle analysis techniques. The work primarily focuses on evaluating the efficiency of the UAV assisted precision agriculture system. The proposed framework can be utilized for predictive maintenance by identifying the performance of the UAV assisted precision agriculture system. This can improve the sustainability of the precision agriculture system.

Borah et al.[13] studied that on applying AI assisted drone technology for precision agriculture. The work primarily focuses on intelligent monitoring of the precision agriculture system. The proposed framework can be utilized for predictive maintenance by identifying the performance of the precision agriculture system. This can improve the sustainability of the precision agriculture system. Arsenoaia et al.[14] propose a comprehensive review of agricultural drone technology. The work primarily focuses on applying drone technology for precision agriculture. The proposed framework can be utilized for predictive maintenance by identifying the performance of the precision agriculture system. The proposed data pipeline for Decisive Grade agronomy is as shown in Fig1. This can improve the sustainability of the precision agriculture system.

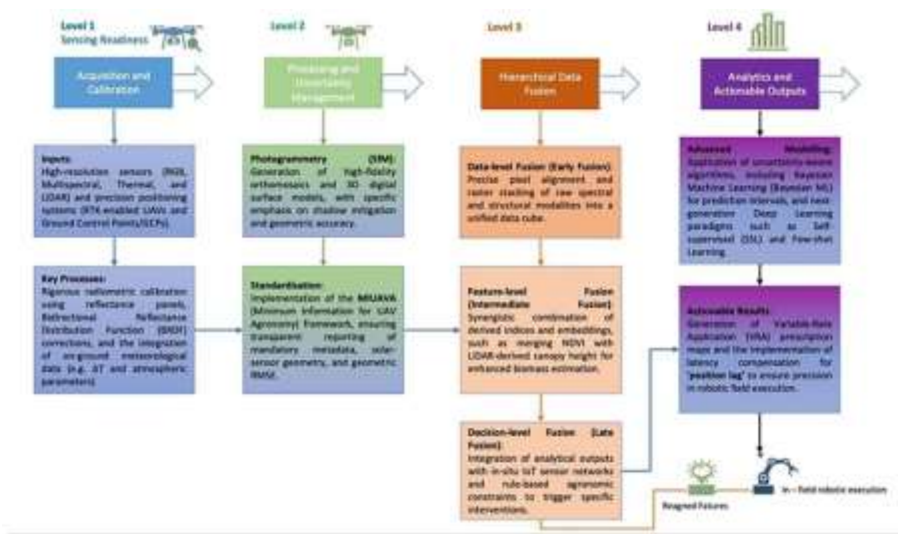

Fig.1. Representation of end-to-end data pipeline for Decision-Grade Agronomy [14]

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The research area of the research by Renuka[15] is based on artificial intelligence technology using predictive analytics for precision agriculture, especially for data modeling predictions. The research is based on the application of machine learning and regression for data analysis for agricultural purposes to improve the decision making process. The research contributes to the predictive maintenance process by identifying the anomalies in the operation of the agricultural system by drones at an early stage to improve the efficiency of the agricultural system. Kumar and Choudhury's[16] research is based on the application of machine learning algorithms for precision agriculture to monitor and manage the agricultural crops. The research by Kumar and Choudhury indicates the application of data driven approaches, especially regression, to process the data for environmental purposes. The research contributes to the predictive maintenance process by critically evaluating the operation of the agricultural system to identify the defects in the operation of the drone based agricultural system.

Ugwu et al.[17] analysis and research is based on the application of machine learning and artificial intelligence algorithm approaches for the management of the crops using the systematic literature review method. The research by the authors is based on the application of data driven approaches for the efficient operation of the agricultural system to improve the productivity of the crops. The research contributes to the predictive maintenance process by applying the analytical approaches to identify the anomalies in the operation of the agricultural system by drones. The paper presented by Ali et al.[18] provides an in depth discussion on the application of artificial intelligence technologies in developing sustainable crops. In this paper, the authors discuss the application of machine learning, deep learning, and data analytics in improving efficiency in the agricultural sector. The paper provides an overview on the application of regression models, which is applicable in developing predictive maintenance.

Mohyuddin et al.[19] research provides an overview of the evaluation of the application of different machine learning techniques in developing precision farming in smart agriculture systems. In this paper, the authors have discussed the application of supervised learning techniques, unsupervised learning techniques, and regression techniques in assessing data obtained from the agricultural sector. For instance, they discussed how the crop phenotypes are observed and analysed using crop phenotype communication network depicted in Fig2. This paper is relevant in developing predictive maintenance because it provides an overview. Melki et al.[20] research about and studied the application of different technologies, including artificial intelligence, drones, robotics, and sensor networks, in developing sustainable agriculture systems. This research paper has provided an overview of the importance of intelligent data processing in developing efficient smart agriculture systems. This research paper supports the predictive maintenance concept because it provides an overview of real-time monitoring techniques that can be used in developing predictive maintenance.

Fig.2. Flowchart depicting crop phenotyping communication network [19]

Pramanik et al.[21] and his team researched together and provided an outline of the application of different data driven mathematical modeling techniques in developing smart agriculture systems. This research paper has provided an overview of the application of different mathematical modeling techniques in developing crop monitoring systems using drones. This research paper also provides an overview of different statistical modeling techniques used in analyzing complex data obtained from crop monitoring systems using drones. This research paper supports the predictive maintenance concept because it provides an overview of different mathematical modeling techniques used in developing predictive maintenance. The research by Melesse[22] explains about the application of digital twin technology in developing crop monitoring systems using drones. This research paper creates a digital model of a real world crop monitoring system using drones. This research paper has provided an overview of real time monitoring techniques used in developing predictive maintenance in smart agriculture systems. This research paper supports the predictive maintenance concept because it provides an overview of real-time monitoring techniques used in developing predictive maintenance.

2.2 Challenges in Advanced Technological Implementations:

Mundappat Ramachandran, et al.[23] discussed some of the challenges associated with drone based agricultural monitoring, which is related to energy dependency, data processing, and decision making. The application of solar energy and deep learning techniques is also associated with some problems. Another problem associated with this approach is related to the accuracy of AI models in various environmental conditions, which is a major problem in predictive maintenance. Seethapathy, et al.[24] faced some of the challenges associated with early anomalies in AI models for predictive maintenance, which is related to variations in real field conditions, data inconsistency, and a lack of labeled data. Another problem associated with AI model accuracy is related to environmental noise and crop diversity. Ensuring the accuracy of AI models in various environmental conditions for predictive maintenance is a major problem.

Hassan[25] having some of the challenges associated with AI based predictive maintenance systems for agricultural purposes, which is related to accuracy in large scale sensor data and false predictions for predictive maintenance. Another problem associated with the application of AI based predictive maintenance systems for drone based agricultural purposes is related to limited computational capabilities and environmental variations. Almannaei[26] went through some of the key challenges associated with predicting battery failure for drone based agricultural purposes using machine learning techniques, which is related to limited failure history, usage, and environmental factors. Another problem associated with machine learning techniques for predictive maintenance is related to ensuring high accuracy for predictive maintenance.

In their paper, the Elufioye et al.[27] have presented some of the factors that affect the predictive analytics used in AI system development for the agricultural supply chain. These factors, in turn, affect the maintenance and efficiency of the drone based agricultural system. For example, the fluctuating demand for the products makes it hard to make predictions. In their paper, the Singh et al.[28] have observed some of the factors that affect the integration of the IoT and AI system in the management of the agricultural supply chain. These factors, just like other systems, make it hard to rely on the accuracy of the crop prediction model. For example, the accuracy of the crop prediction model is dependent on the quality of information received from the sensors.

In their paper, the Elbasi et al.[29] have commented on the factors that affect the development of the green AI system for the management of the agricultural supply chain. These factors, just like other systems, make it hard to design an efficient predictive maintenance system, especially for the drone based system. For example, the power available makes it hard to design an efficient predictive maintenance system. Sudha and Loret[30] highlights some of the key challenges that are encountered when using machine learning for precision agriculture. Just like other systems, they pose a challenge when it comes to designing an efficient predictive maintenance system, especially for the drones. For example, the precision of the monitoring system is dependent on the precision of the sensors, weather, and other factors.

III. CONCLUSION

The importance of the role of regression based mathematical models, as a key player, has been highlighted as a vital factor for the development of predictive analytics, which provides precise estimates of crop health, environmental, and equipment performance. The inclusion of digital twins, autonomous technologies, and data driven approaches has also been highlighted as a key factor for the development of enhanced capabilities for drone assisted agricultural environments. However, there are a number of limitations and challenges to the implementation of such technologies in precision agriculture. For instance, there is a problem of data inconsistency, a lack of availability of high quality labelled data, and environmental factors affecting model accuracy. Other limitations include computational, energy dependency of drones, imprecise sensors, and difficulties in integrating AI, IoT, and drone based technologies. The existence of noisy data and scalability also makes it difficult to implement efficient predictive maintenance approaches. The future innovations for the development of efficient drone based crop monitoring systems include advancements in more robust AI models, enhanced regression approaches, and adaptive learning systems to cater to changing agricultural environments. In addition, advancements in edge computing, sensor precision, and data processing will also enhance decision making capabilities. Furthermore, advancements in explainable AI and digital twin technologies will also improve system transparency, reliability, and overall sustainability.

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