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SCOPE OF AI IN AGRICULTURE

Abstract

Artificial Intelligence (AI) plays a crucial role in revolutionizing agriculture, addressing the labor-intensive nature of the field. The advancements in AI have brought about increased ease and precision to agricultural practices. AI methods guarantee the timely implementation of management strategies, leading to improved yields and increased income for farmers. In this paper, we delve into the AI techniques applied across different phases of cultivation, exploring how these methods enhance the effectiveness and productivity of agricultural practices. Detailed explanations are provided for each phase, with the specific algorithms employed to implement these technologies.

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I. INTRODUCTION

The global population is experiencing rapid growth, leading to a substantial increase in food demand. The agricultural sector emerges as a pivotal focal point requiring immediate attention in light of these circumstances. The adverse effects of climate change pose significant threats to crop production, exacerbating concerns related to food scarcity. The situation may worsen in the future due to both growing population numbers and drastic shifts in climate conditions.

Presently, the agricultural sector faces with a multitude of uncertainties stemming from climatic variations, water supply demands, soil degradation, labour shortage, pest outbreaks, and fluctuations in the pricing of agricultural machinery. This uncertainty, in turn, poses challenges for farmers, impacting their income and overall livelihoods. Efficient monitoring of crop production and marketing becomes imperative to address these uncertainties effectively. Recognizing the complexity of these issues, AI emerges as a pivotal solution. AI techniques facilitate the analysis of various factors integral to agriculture, including soil parameters, plant parameters, and weather conditions. By analysing these parameters, AI techniques predict the future scenarios and provide farmers with strategic management recommendations, thereby mitigating uncertainties and enhancing the overall resilience of the agricultural sector.

AI plays a pivotal role in empowering machines to emulate human intelligence, undertaking tasks such as learning, recognition, and decision-making [1]. In the expansive realm of AI, Machine Learning (ML), Deep Learning (DL), Image processing and, Computer vision stand out as critical subfields that collectively drive the evolution and application of intelligent systems [2]. ML, by enabling computers to learn from data and make predictions without explicit programming, forms the foundational framework for intelligent decision-making. DL, a subset of ML, harnesses the power of neural networks with multiple layers to model intricate patterns, proving particularly effective in tasks like image and speech recognition. Simultaneously, image processing and computer vision focus on the interpretation and understanding of visual data, essential for applications ranging from facial recognition to autonomous vehicles. Together, these subfields synergize to propel AI's capabilities, underpinning advancements across industries and reshaping our interaction with technology in profound ways. These technological advancements have profound applications across diverse industries, spanning medical, industrial, image processing, financial sectors, and market analysis. In the agricultural sector, AI serves as an indispensable tool by deciphering data related to plants, soil, and crops, providing farmers with invaluable insights and recommendations to optimize yields.

AI plays a crucial role in each stage of cultivation, from supporting the crop planning phase to growing and facilitating the harvesting process [3]. Farmers can decide the crop to be cultivated with the help of AI based crop selection, weather forecasting, price prediction, and yield prediction. Robots and drones powered by AI are utilized for land preparation and precisely seeding plants. AI-controlled soil management monitors soil quality, assists in crop selection, and determines fertilizer requirements. In the crop maintenance phase, AI technology is employed in weed detection, predicting disease and pest and supporting irrigation. Additionally, AI-based solutions for timely harvesting, grading, and packaging represents application in the crop harvesting phase. Figure 1 shows the general architecture of the AI based systems in agriculture applications.

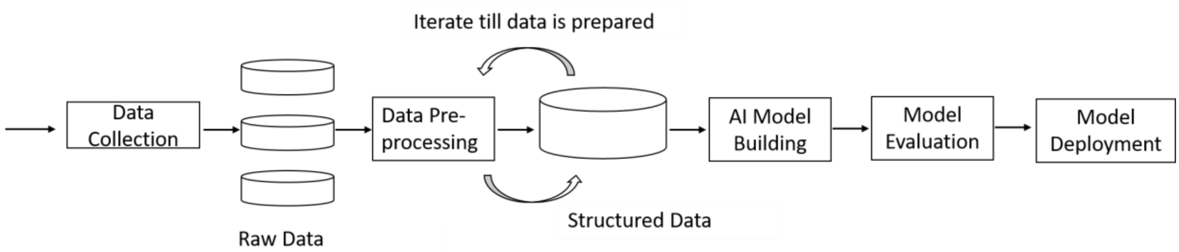

Figure 1: Architecture of AI workflow for agricultural applications

II. APPLICATIONS OF AI IN PLANNING PHASE

AI plays a pivotal role in the resource planning of cultivation, particularly in crop selection. The application of AI techniques proves highly beneficial in assisting farmers in choosing crops that maximize profitability. By leveraging AI-based forecasting techniques, farmers receive timely and informed insights, enabling them to take proactive actions and make well-informed decisions. This integration of AI in resource planning not only enhances the efficiency of crop selection but also empowers farmers to optimize their agricultural practices for improved profitability and sustainability**.**

Crop Selection

The appropriateness of a crop for a specific piece of land and its resulting yield is depends upon various factors such as soil quality, climate conditions, and geographical features. Unpredictability in weather patterns, making it challenging for farmers to anticipate conditions accurately. This unpredictability can pose challenges in choosing the right crops and managing farming practices effectively. This underscores the significance of crop selection, particularly in the current era. AI can assist farmers in selecting the most suitable crops for their land, taking into account factors like soil composition, climate conditions, land topography, elevation and altitude, water availability and sources, pests and diseases prevailing in the area, marketing and transportation infrastructure, as well as the availability of labour in the area. Additionally, AI aids in crop sequencing by providing a sequence of crops that can maximize yield over a given season.

Different methods are available which predicts suitable crop for an area, yield per area, crop name etc. along with sequencing technique. First phase of this work will be, collecting suitable dataset for prediction, which will include various soil characteristics (such as EC, Ph, Nitrogen, Phosphorus, Pottasium, Zinc, Iron, Soil type etc), Climatic Parameters (Temperature, Humidity, Rainfall, Wind, Season etc), Production (Area of cultivation, Production under area) etc. Of this climatic data can be used for predicting the future weather and the resultant data can be used for predicting suitable crops. Then the major influencing or relevant features for crop selection will be extracted from the collected dataset. Recursive Feature Elimination (RFE) and Modified Recursive Feature Elimination (MRFE) can be used for this purpose. As a next step, suitable crop or yield can be predicted by using classification algorithm such as Decision tree algorithm, Random Forest, bagging classifier, ANN, Polynomial Regression, Naive Bayes etc [4].

Weather Forecasting

The significant impact of sudden and unpredictable changes in weather patterns on farming, especially in precision agriculture, is clear. Climate change stands out as a formidable challenge for farmers, contributing to the depletion of water resources, diminishing soil fertility, heightened pesticide use, and a decrease in overall crop productivity. The ability to accurately predict weather conditions has become pivotal in alleviating these challenges and optimizing agricultural methodologies. The convergence of AI techniques with Internet of Things (IoT) devices has proven to be pivotal in the realm of agricultural weather prediction and climate impact mitigation. Advanced AI and ML algorithms, such as the Adaptive Neuro-Fuzzy Inference System (ANFIS), are leveraged to analyze data sourced from weather stations and IoT sensors [5]. These algorithms utilize various parameters, including maximum temperature, minimum temperatures, humidity, and wind direction, to forecast future weather conditions. Moreover, Recurrent Neural Network (RNN) models, particularly those employing long short-term memory (LSTM), surpass alternative machine learning models in precision regarding rainfall forecasts [6]. The LSTM architecture's ability to retain information over extended periods proves advantageous in encapsulating the temporal dependencies inherent in weather data.

These AI and machine learning models not only facilitate the prediction of weather patterns but also empower farmers to make informed decisions concerning irrigation, fertilization, and other preventative measures. The timely and accurate forecasting of weather conditions enables farmers to optimize their agricultural practices, minimize risks, and enhance overall productivity and harvesting.

Yield Prediction

Accurate yield forecasts empower farmers to optimize resource allocation, enhancing efficiency and sustainability. From financial planning and supply chain management to climate resilience and precision agriculture, yield predictions inform critical decisions at various levels. In the swiftly evolving climate and market conditions, the capacity to foresee and strategize for crop yields not only secures economic sustainability for farmers but also cultivates a more robust and productive agricultural sector as a whole.

Multiple factors impact crop yield, and uncertainties are inherently linked to the process of cultivation. The feature includes soil parameters, climatic information, cropland information, groundwater characteristics, vegetation indices, fertilization information, phenology data, cropland information etc. The general architecture for yield prediction includes, data collection, data pre-processing, training using machine learning algorithms and prediction using the generated model. Regression such as LR, MLR, MARS, K-nearest neighbours, Support Vector Machine, Decision tree, Random forest, ANN, deep neural network, convolution neural network and LSTM algorithms can be used for model creation [7]

Price Prediction

The agricultural sector grapples with significant uncertainty, particularly in areas such as crop prices, which can profoundly impact farmers' incomes. Timely selling of crops is crucial, and its success is often hindered by uncertainties influenced by government policies, climate conditions, and crop availability. AI based forecasting emerges as a valuable tool to address these challenges. AI technologies leverage historical data encompassing market trends, crop prices, and diverse influencing factors. Through the analysis of this data, predictions can be made to guide farmers in making timely and informed decisions. This approach is instrumental in mitigating financial losses and optimizing resource utilization.

By harnessing AI, farmers gain insights into the dynamic nature of crop prices, allowing for intelligent decision-making regarding when and where to sell their produce. This proactive stance significantly reduces the risks associated with price fluctuations. Informed by AI predictions, farmers can strategically engage with buyers and markets, enhancing their overall economic outcomes. Several ML algorithms, such as Artificial Neural Network (ANN), Generalized Neural Network (GRNN), Support Vector Regression (SVR), Random Forest (RF), and Gradient Boosting Machine (GBM), are widely employed for crop price prediction[8]. These advanced algorithms contribute to the precision and reliability of forecasts, empowering farmers to navigate the uncertainties inherent in the agricultural sector. In essence, AI-based forecasting serves as a powerful ally for farmers, offering them the tools needed to thrive in a complex and dynamic environment.

III. APPLICATIONS OF AI IN SOWING PHASE

The sowing phase in plant cultivation is a critical initial stage where seeds are planted and germinate to form seedlings, laying the groundwork for the entire growth cycle. Key considerations include selecting suitable seeds, providing optimal germination conditions, and caring for emerging seedlings. Modern agriculture sees a pivotal role for AI-driven robots and drones. These technologies utilize AI algorithms to analyze terrain and environmental conditions, aiding in the identification of optimal cultivation land. AI-based soil management systems further enhance the process by continuously monitoring soil quality, offering insights for crop selection and precise fertilizer application. This data-driven approach boosts agricultural efficiency, empowering farmers to make informed decisions that optimize resource use and encourage sustainable practices. Integrating AI into land selection, seeding, and soil management results in increased precision and productivity, contributing to more effective and environmentally conscious farming methods.

Robotic Seeders

AI technology enables robots to exhibit intelligence in their tasks, automating various farming activities and enhancing precision. AI-based robots are deployed across all facets of agriculture, including seeding, crop maintenance, harvesting, and packing. AI technology empowers robots to demonstrate intelligence in farming tasks, automating diverse agricultural activities and elevating precision. Robotic seeders, a testament to this advancement, streamline the planting process across vast farmlands, ensuring precise seed placement and fostering optimal plant spacing for consistent growth. The integration of AI extends to seed selection, where it assists in identifying the most suitable seed varieties by considering factors such as climate, soil type, and historical performance data. Moreover, equipped with sensors, these robots actively monitor crop health in the early stages, enabling timely interventions to address potential issues [9]. This convergence of AI and robotics not only enhances operational efficiency in agriculture but also contributes to informed decision-making and sustainable farming practices.

Soil Mapping

Soil is a critical resource that must be efficiently utilized for successful cultivation. One of the greatest challenges facing agriculture today is soil degradation, leading to significant yield losses. Each crop has unique soil nutrition requirements, making it essential for soil management techniques to address these issues and generate effective management strategies. AI-based systems play a crucial role in soil mapping, monitoring, remediation, and optimization to enhance cultivation practices.

Soil mapping is the process of analysing the characteristic of soil which help farmers to make selection of crops and land use. In soil mapping, AI technologies leverage remote sensing techniques, satellite imagery, and survey data to create detailed soil maps. These maps aid in planning land use and selecting suitable crops for a region. Various AI algorithms, including Multiple Linear Regression (MLR), K-Nearest Neighbors (KNN), Support Vector Regression (SVR), Cubist, Random Forest (RF), and ANN, are employed for accurate soil mapping[10].

IV. APPLICATIONS OF AI GROWING PHASE

AI plays a crucial role in the crop monitoring phase, AI based drones widely used for crop monitoring purpose. Soil management, weather forecasting, disease and pest management, irrigation management, and yield prediction constitute key aspects of plant monitoring. AI is employed with high efficiency in these areas to enhance precision and decision-making.

Drones

AI-based drones have become integral in modern agriculture, offering farmers a rapid and comprehensive overview of their farmland. These advanced drones find applications in crucial areas such as crop monitoring, pesticide spraying, and weather monitoring[11]. Outfitted with high-resolution cameras, these drones capture detailed images of the farmland. Through the technique of image stitching, these images are seamlessly combined to form a complete representation of the entire agricultural area. AI algorithms play a pivotal role in analyzing these images, identifying signs of pest infestations, diseases, and nutrient deficiencies in plants.

The advent of AI-based drones has revolutionized pesticide spraying, significantly reducing the environmental impact. AI algorithms enable drones for precise targeting of pesticide application only in areas where it is necessary, eliminating the need for uniform spraying as in traditional methods. This not only resolves environmental concerns associated with excessive pesticide use but also contributes to cost savings for farmers by avoiding unnecessary pesticide expenditures.

In addition to crop-related applications, AI-based drones are equipped with various sensors including temperature, humidity, and barometric pressure sensors. These sensors collect real-time data on weather conditions. Through sophisticated AI algorithms, this data is analyzed to provide accurate weather forecasts, aiding farmers in making informed decisions. Random forest, Decision tree, Support vector machine, Gradient boosting are some of the ML algorithms used in weather forecasting.

Crop Monitoring Robots

In crop maintenance, these robots perform tasks like weeding, monitoring, and applying fertilizers and pesticides as needed, leveraging sensors and cameras to detect plant characteristics indicative of disease or pest infestations. Timely intervention by farmers can be facilitated to safeguard the health of the crops. Particularly valuable in harvesting, AI-based robots efficiently locate ripe crops, ensuring timely harvesting for sale without compromising quality. Through the application of image processing techniques, captured images of crops undergo analysis. ML algorithms, specifically ANN, are employed to identify and classify distinctive features within the images. This enables the automated categorization of crops based on their unique characteristics [12].

Soil Monitoring and Redemption

Soil monitoring, another vital application of AI in soil management, involves the assessment of soil quality. Using IoT sensors, AI techniques collect data on soil parameters such as moisture, salinity, ground temperature, and erosion. Analyzing this data assists farmers in making informed decisions, improving crop yield, and reducing the use of harmful pesticides and fertilizers. Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) are widely used algorithms for processing data collected through IoT sensors[13]. For restoring the quality of contaminated soil, soil redemption techniques are applied. Sensors equipped with AI algorithms can detect the presence of contaminants, enabling farmers to make informed decisions about management strategies and crop selection. Support Vector Machines (SVM), Decision Trees, Random Forests, K-means clustering, and hierarchical clustering are commonly used AI techniques to classify soil samples based on contamination level.

Given the scarcity of soil as a vital resource, its effective use is paramount in the contemporary world. Enhancing soil quality, a factor directly influencing crop yields, is attainable through well-suited soil optimization methods. AI-empowered techniques play a pivotal role in soil optimization by forecasting soil behavior under various scenarios, aiding farmers in adopting appropriate management strategies. The commonly used AI techniques in soil optimization are multiple linear regression (MLR), decision trees or support vector machines and ANN [14].

Disease and Pest Detection

The presence of crop diseases and pests can deeply influence agricultural yields, posing significant challenges to global food production. The consequences of this includes reduced yields, quality degradation, economic losses, increased production costs, food insecurity etc. In the advanced stage of plant diseases, farmers will be forced to use chemical pesticide to ensure the yield production. The use of these control methods will have serious environmental consequences such as water contamination, air contamination, loss of biodiversity etc. So early detection and proper management are crucial to prevent pest and diseases and ensure a stable and sufficient food supply for the population. Typically, diseases are identified through visual observation or laboratory testing. However, the lack of domain experts can impede precise early disease diagnosis and treatment, affecting timely management. Traditional monitoring and diagnostic methods are often labor-intensive, time-consuming, and reliant on human expertise, which proves inadequate for the swift and large-scale detection of diseases essential for safeguarding our agricultural system. Consequently, there is a need to adopt a precise, rapid, and cost-effective method for diagnosing agricultural illnesses. Image-based automatic disease identification emerges as a solution, enabling early detection by various stakeholders such as farmers and extension personnel in the field, eliminating the need to consult an expert and facilitating prompt intervention. Early diagnosis and treatment not only prevent disease progression but also enhance plant health and contribute to managing the spread of specific diseases.

The challenges associated with identifying plant diseases and pests have been tackled by the promising domain of artificial intelligence. Techniques such ML and DL have been applied to disease detection, marking substantial progress in this field in recent years. The process includes data collection, image pre-processing, feature extraction, model training, validation and testing. A diverse dataset of images encompasses of various types of diseases will be collected as part of data collection. Then collected data set will be pre-processed using various image processing techniques. After that, dataset will be randomly partitioned into training and testing dataset. Relevant features will be extracted from preprocessed images. These features serve as the input for the ML model. Later, model will be created using a ML or DL algorithm. The accuracy of the generated ML model will be tested by using testing data set. The main objective of the generated model will be the accurate identification of the diseases and the percentage of disease spread [15]. Disease and pest occurrences in crops are intricately linked to weather conditions, and accurate prediction is crucial for effective management. Utilizing weather parameters as predictors through ML algorithms allows for precise predictions. Among various ML techniques, ANN have demonstrated superior performance in comparison to other methods [16].

Weeding Management

Weeds pose several significant problems in agriculture, affecting crop yield, quality, and overall farm productivity. Weeds compete with crops for essential resources such as sunlight, water, and nutrients. Their rapid growth and aggressive nature can lead to stunted crop growth and reduced yields. Overreliance on herbicides as a primary weed control method can lead to the development of herbicide-resistant weed populations. Also the use of chemical herbicides to control weeds can have environmental consequences, such as soil and water pollution. Manual weeding involves the physical removal of weeds by hand or using hand tools. It is labor-intensive and time-consuming, often leading to increased operational costs for farmers. Automated weeding techniques in agriculture address critical challenges faced by farmers, offering a solution that is both efficient and sustainable. Automated weeding systems, equipped with technologies such as computer vision, ML, and robotics, significantly reduce the reliance on manual labour. By automating the weeding process, farmers can achieve higher levels of precision and speed, enabling them to cover larger areas in a shorter time frame. This not only enhances operational efficiency but also frees up human labour for more skilled and strategic tasks on the farm. Moreover, automated weeding contributes to sustainable farming practices by minimizing the use of herbicides and other chemical inputs.

The most important task of the weed detection system is to differentiate crop seedling and weeds and it is a difficult task considering the intra-class variations. Plant weed detection involves: Image acquisition, pre-processing, feature extraction and training the model and testing model. Data Acquisition involves, collection of datasets with different types of crops and weeds. It can be done using UAVs, Field Robots, Handheld Cameras etc. image processing techniques like green component segmentation, colour enhancement, background removal, image enhancement, resizing etc. can be done during pre-processing. Also image augmentation techniques can be implemented to enlarge the size of training data. Apply different annotations techniques, such as bounding boxes annotation, pixel-level annotation, image-level annotation, polygon annotation, and synthetic labelling if needed. Then extract features like shape, texture, colour etc. and create the model using any classifier such as Neural Network, Random Forest and Support Vector Machine or apply DL for classification[17].

Irrigation Management

Irrigation has significant role in agriculture as it directly influences crop growth and yield. Farmers often face challenges in optimizing irrigation practices due to factors such as varying soil moisture levels, unpredictable weather patterns, and the need to efficiently manage water resources. Inefficient irrigation not only affects crop yields but can also contribute to water wastage, environmental degradation, and increased production costs. The application of AI in irrigation has revolutionized traditional farming practices by introducing precision and efficiency into the management of water resources. Intelligent irrigation approaches, which judiciously apply water in precise amounts and at optimal timings, play a pivotal role in good plant growth and, consequently, enhancing crop productivity.

AI technologies, including sensors, drones, and ML algorithms, enable farmers to collect and analyze real-time data on soil moisture levels, weather patterns, and crop conditions. Various studies shows that, Neural Network can be used for estimating irrigation flow prediction, evapotranspiration prediction, leaf temperature using crop water stress index, water stress detection. Fuzzy logic-based technologies are widely used for building Decision Support Systems software for irrigation management. SVM, Decision Tree, Regression and the combination of these algorithms can be used for evapotranspiration estimation, recommendations of an agronomist for one year of irrigation management, soil water content prediction and irrigation management[18].

V. APPLICATIONS OF AI IN POST HARVESTING PHASE

AI is extensively utilized in the harvest and postharvest phase of crop management, addressing critical steps such as timely harvesting, grading, and packaging, which are essential for maximizing income for farmers. The effectiveness of these processes directly influences the financial outcomes of their hard work. AI interventions ensure efficiency and accuracy throughout these stages, from optimizing harvest timing to precise grading and packaging. Additionally, AI contributes to identifying suitable markets, further enhancing the overall profitability of farming endeavours. Through its comprehensive approach, AI in the post-harvest phase plays a pivotal role in streamlining operations and ensuring fruitful outcomes for farmers.

Harvesting Management

AI significantly enhances precision and accuracy in the harvesting process by leveraging computer vision and image processing, two pivotal techniques within the AI domain. These technologies empower the creation of robots capable of identifying ripe crops and executing the harvesting task without causing damage. The AI-enabled systems meticulously assess crop features such as color, size, and shape to determine their grade, thereby improving overall agricultural practices and aiding in market identification. ML algorithms contribute by optimizing the arrangement of crops in packing containers, maximizing space utilization while minimizing the risk of crop damage. The analysis of obtained images adds a layer of intelligence to the process. K-Nearest Neighbors (KNN), Decision Tree (DT), Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Support Vector Machine (SVM)—are commonly used in ML algorithms in the harvest management [19].

VI. CONCLUSION

The detailed examination of AI applications in every phase of cultivation underscores its pervasive impact on agriculture. The study demonstrates that AI has widespread applications throughout the agricultural process, aiding farmers in enhancing their income through improved practices. While AI techniques undoubtedly contribute to increased productivity, addressing the challenge of implementing these technologies at a reasonable cost is crucial to ensuring their accessibility and affordability for farmers. Balancing the benefits of enhanced agricultural practices with cost-effective implementation is key to maximizing the positive impact of AI in farming communities.

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