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Research Article

Digital Transformation of Agriculture: The Future of Farming

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ABSTRACT

The agricultural sector is frequently described as the foundation of human civilization. Moreover, one of the key industries in ensuring food security is agriculture. So, it becomes very critical to keep optimizing the agricultural practices to meet the increasing needs over the decades. It is estimated that the world will have an additional 2 billion to feed by 2050.Traditional agricultural practices may not be sufficient to cater the future needs. More over the resources like water, fertile soil may deplete overtime. So, in the vision of sustainability we need modern approaches. This is where Agriculture 4.0 comes into the picture. Agriculture 4.0 provides insights into digitalization of agriculture using various technologies. We will be highlighting a few of the technologies used in the digitization process, like robots, IoT, sensors, AI&ML in this paper. The productivity boost that these technologies provide is substantial. Digital agriculture provides creative ways to reduce climate risk, maximize resource use, and raise agricultural yields by facilitating real- time data collection, predictive modelling, and data-driven decision- making.

Keywords: Digital Agriculture, Agriculture 4.0, Digitization of Agriculture, Internet of things, Smart Agriculture ,Precision farming,Data Analytics, AgriTech

1. Introduction:

Agriculture is one of the oldest practice's humans have been following from ancient times. Over the years, agricultural practices and methodology have drastically changed Agriculture is also one of the Greatest sources of income for the rural areas and greatly help to shape rural society affecting both the farmers and the businesses that support the farming population but over the decades, due to rapid industrialization and increased population, there is aneed of modern approach to ensure food security. It is anticipated that by 2050 global population will beincreased from the current 7.7 billion to 9.2 billion, urban population will be rise by 66%, arable land willbe declined by approximately 50 million hectares, global GHG emissions (source of CO_2 – promote crop disease and pest growth) will be increased by 50%, agri-food production will be declined by 20%,and eventually, food demand will be increased by 59to 98% – posing an imminent threat to food securityand adequate food availability [1]. And also due to declining resources and changing climatic conditions, there is a demand for the new approach other than the traditional approach. Here digital agriculture comes into picture. In comparison to other industries it can be seen that the agricultural sector has been left way behind in terms of modern technology so, implementing digital technology involves the automation of various activities, which was traditionally done manually by humans, using the data in optimizing the processes. Many operations, including planning farming operations, financing, reporting, monitoring numerous operations, and performances, are simplified by digital technologies. Digital technologies in agriculture have been deployed in various segments of farming, including farm equip-mentation, animal handling facilities, agronomy, and communication [3]. The main demands of agriculture are increased crop productivity, water efficient, high quality yield,pollution free agriculture and reduced wastage whichcan be actively fixed by data-based agriculture it is also expected that there may be labour shortage overthe decades which demands to shift the agriculture from labour intensive process Moreover, digital agriculture empowers farmers to tailor their practicesto the specific needs of each plot of land. By utilizingdata-driven insights, they can optimize planting patterns, adjust crop rotations, and even predict potential yield variations. This not only boosts productivity but also contributes to soil health and

biodiversity preservation [6]. Also, agriculturalproduce greatly contributes to the nation's GDP. In India, during the financial year 2022-2023 the share of GVA of agriculture and allied sectors in the total economy was 18.3% (https://pib.gov.in/PressReleasePage.aspx? PRID=1909213). This shows how agriculture plays an important role in the development of Country's GDP.

So, in the upcoming sections we will explore more on digital agriculture and the different technologies involved in achieving the same.

2. Digital Agriculture

Digital Agriculture also known as Agriculture 4.0 orSmart agriculture utilizes modern technologies like IoT, Big Data Analysis, Cloud computing, AI, ML, Sensors, Robots etc.... working together streamlinedto get an optimized output. Smart agricultureprovides farmers with a diverse set of tools to addressseveral agricultural food production challenges associated with farm productivity, environmental impact, food security, crop losses, and sustainability[1]. In this Era of data-based engineering, it becomesvery essential to utilize the data available, process it and employ the data according to the needs. Using this data various predictions, patterns and preventivemeasures can be taken. Overall, the adoption and useof Digital agriculture technologies vary across different regions of the world, and are influenced by factors such as access to technology and infrastructure, government policies and initiatives, and investment in research and development [3].Digital agriculture can also be termed as data drivenagriculture. This digitization enables real-time monitoring, data collection, analysis and automated decision-making, leading to more efficient and sustainable agriculture [6]. Smart agriculture enablesthe systems to think and make rational decisionswithout the involvement of the humans or with minimal involvement of the humans.

Not only with the crop production but it also deals with the post harvesting activities like storage optimization, supply chain optimization. Fig.1 represents digital agriculture in a visual manner. It gives the general idea of various technologies involved in smart agriculture. Digital agriculture promotes sustainable practices by optimizing resource use, reducing chemical inputs andminimizing environmental impact. This is key toaddressing challenges such as soil degradation and climate change [6]. As the involvement of humans islesser than the traditional farming practices, the chances of errors reduce, thereby increasing the overall efficiency.

With these advantages with digital agriculture, it is also important to meet consumers' needs at the production and distribution stages through building asystem, which delivers food safety information [8]. Shifting weather patterns such as increase in temperature, changes in precipitation levels, and ground water density, can affect farmers, especially those who are dependent on timely rains for their crops. Leveraging the cloud and AI to predict advisories for sowing, pest control and commodity pricing, is a major initiative towards creating increased income and providing stability for the agricultural community [11].

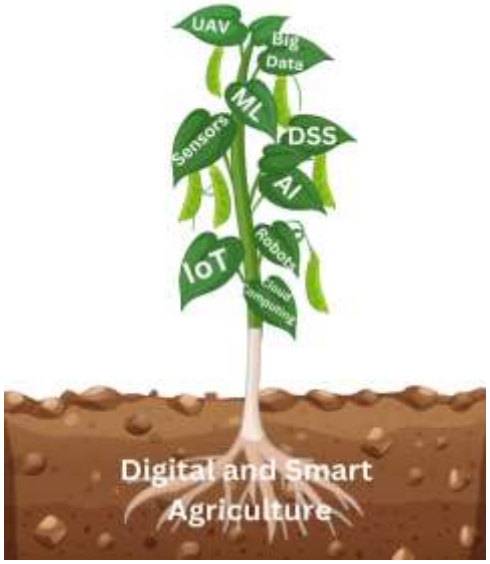

Fig.1. Visual Representation of Digital and smart Agriculture

In conclusion, digitalizing agriculture helps in revolutionizing the traditional farming practices by the integration of various technologies that helps in the optimizing various activities, increasing crop yield, effective and sustainable utilization of the resources, minimizing costs, enhancing productquality and getting maximized profit.

3. Technologies involved in Smart Agriculture

There are various subsystems involved, which work in loop with one another to make a successful smart agriculture system. These include various multi- disciplinary technologies which are in sync together.This section enlists some of those technologies:

3.1. Sensors

Sensors: They play a very major role in the digitalization of the agriculture. They are most important in collecting the real time data using whichwell rationalized decision can be made. They are spatially distributed and arranged for monitoring thephysical conditions of the environment [1]. These sensors may be wired or wireless. These data are thensent to the server or to the field management system based to architecture design. There are various sensors like humidity sensor (used to measure the humidity of soil and the atmosphere or the closed environment), temperature sensor (used to measure the temperature of the environment), cameras (used in surveillance, to detect diseases visually), pH sensor (to analyze the pH of the soil and the water), GPS (for the accurate positioning of the aerial systems), RFID sensors (for the true authentication of the user) etc. The accuracy and precision highly matter as it is the primary information source to the system. There is also a need of error and breakdowndetection in the sensors, so as to prevent any undesired action due to the wrong inputs by thesensors.

3.2. Internet of Things (IoT)

Internet of things, is a technology that creates anetwork of multiple devices or systems which areconnected via internet to the same server. In the case of some wireless networks like Bluetooth, FM based communication the range may be restricted to 0-100Kms, but in contrary IoT removes this range barrier [3]. They enable the user to control and monitor theactivities in the field remotely, when connectedthrough the internet. Generally, the receiver node inIoT-based monitoring systems uploads data to a webserver so that any client device connected to the internet may access it [3]. The transmission of this data takes place in the network layer, the design of which depends on the selection of suitable communication technologies relevant to the field size, farm location, and type of farming method [1].

3.3. Cloud Computing

Cloud computing is one of the most widely used service in this modern era of digitalization. Cloud computing is a technology where integration of multiple devices and systems occurs which may or may not be present at one place. It performs various tasks such as data storage, management and retrieval,and computing. The programs of AI, ML, DSS use the data and computation services provided by cloudcomputing. It enables remote collaboration and data sharing among stakeholders [6]. This eliminates the need of physical hard drives and powerful CPU's at the location to facilitate computation with required speed. As smart agriculture is data driven and generates a lot of data, it is not feasible to keep a physical data storage system at the location. Even thecloud services provided by many service providers gives the flexibility to expand for higher specifications without much costs, which is not true in the case of traditional data management systems.

3.4. Artificial Intelligence (AI)

The systems or machines which can think, analyze, posses' intelligence to make human like rational decisions are known as artificial intelligence. When systems like AI, IoT, and big data, Cloud computing,in line with machine learning (ML), Neural networks, Natural language processing and deep learning (DL), is regarded as one of the key drivers behind the digitization of agriculture [1]. Various data collected by the sensors are analyzed by the AI models and readily makes decision. Integratedmodelling and data analytics include image analytics,identification of crop phenology and yield estimationand crop health monitoring [2]. In agriculture, disease detection of the plants, weed detection, nutrients deficiency analysis by the symptoms shownby the plants visually, un-authorized person detectionin the field, pests attacks on the crop, automatic harvesting and many other technologies readily makeuse of AI to analyse and make decision. Various other processes like irrigation, fertilizers addition to the soil, spraying pesticides can also be controlled by the AI. Many processes can also be optimized with the help of AI.

3.5. Machine Learning (ML)

Machine learning is known for analyzing the data, forming the relationships with the datasets, and generating a model which are majorly used in prediction. There are various models like SLR, MLR,Decision trees, Logistic regression etc... which can generate an equation of the desired output by using the dependent variables. Machine learning tools are used in prediction, clustering, and classification problems, which uses the data stored in the cloud, which was preprocessed based on needs on the cloud[3]. This is a boon to the agricultural sector as it is highly dependent on data and correction prediction using these data can provide a farmer with very highyield and higher profitability. By the data of the season, climate, surrounding temperature, rain cycles, soil conditions and market demand in past and markets demands in the harvesting season can beutilized to make a prediction of which crop would bemore fruitful and provide highest yield and

profits. Various options can be generated and using the AI perfect fit crop can be chosen. Later, early predictionof symptoms, stopping irrigation when rain is predicted, and based the data of the particular crop like water requirements at different stages, temperature requirements, most common diseases ofthe crop can be used to predict and make suitable decision using AI.

3.6. Robots and UAVs

Once required decisions are made it is no required totake necessary actions to make the required changesor work. This is where robots, unmanned ground vehicles and unmanned aerial vehicles comes into picture. Unmanned ground vehicles or robots aresystems that operate on the ground without an activehuman operator. The main components of UGVs generally include; a platform for locomotive apparatus and manipulator, sensors for navigation, asupervisory control system, an interface for the control system, the communication links for information exchange between field management system [1]. Activities like weed removal, plucking the plant which is affected by the disease, harvesting,spraying of the pesticides etc... are readily done usingthis. The increasing demand for accurate field

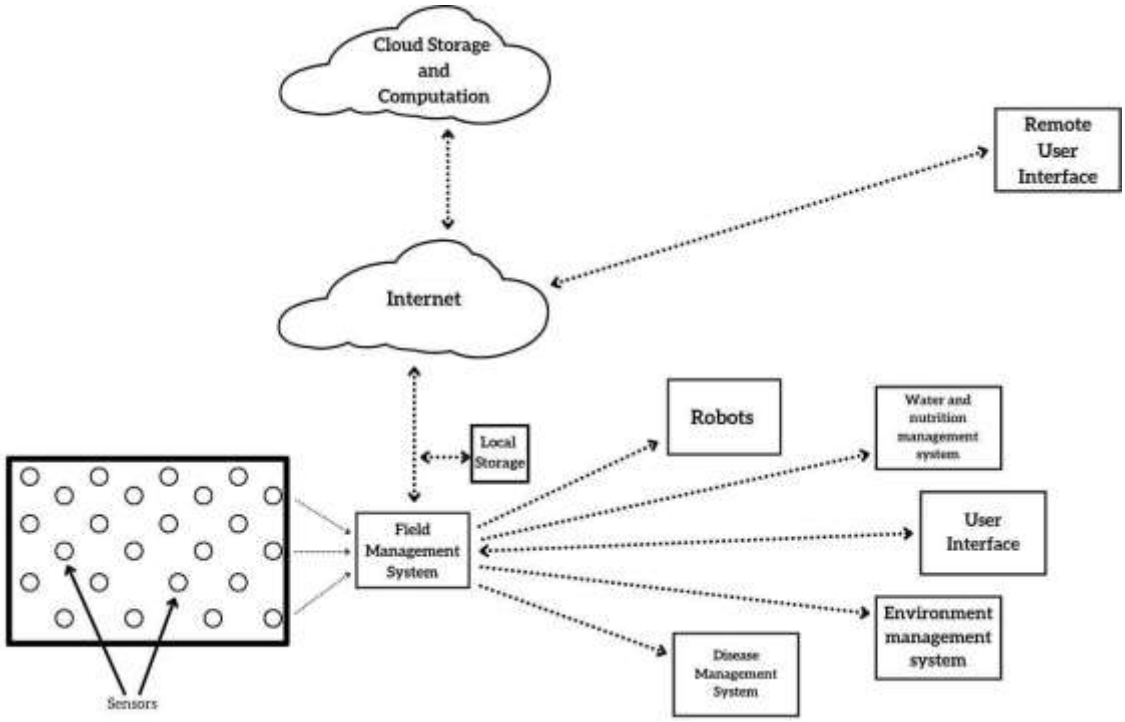

Fig.2. Architecture of Smart Agricultural System

operations, while reducing the farming inputs and environmental impact, demand usage of robotic platforms as the alternative for the conventional tractors and implements [9]. Small sized, electricallydriven platforms are employed for a wide range of tasks, such as light ploughing, spraying, fertilizing, and harvesting. On the other hand, UAVs are the aerial vehicles makes flight without a human onboard. It is found that pesticides when sprayed by UAVs are more effective than other means. UAVs are of various types which can depend on the application. UAVs are also used for the image capturing from a height, which can serve as useful data by some AI or ML models.

4. Architecture of the Smart Agriculture

The fig.2 represents the basic architecture of thesmart agricultural system. All the sub systems discussed in the previous section are in lined inrequired patterns to obtain desired outcome. Thearchitecture begins with the sensors. Various kinds ofdata are generated by the sensors and are directed towards the field management system. Field management system is the brain of the field. It is connected with the internet and facilitates smooth transmission of data through the internet to the servers. This may even have local storage for storing some of the confidential data or small and temporarydata. Required data is sent to the server where it is stored and processed. Once required computation is done, the data is received back to the fieldmanagement system. This system then based on the actions to be performed assigns the tasks to the localsystems. Field management system is connected to the user interface to interact with the user. Thanks toIoT, the user interface can also be remotely accessedthrough the internet connected authenticated system.
In certain cases, if the sub systems are equipped withadvanced technologies, the field management system can be eliminated and the data can be directly routedto the IoT servers through the internet.

5. Conclusion

With worries about the world's food security growingand sustainable farming methods becoming more and more important, the incorporation of digital technologies—known as Agriculture 4.0—becomes a vital remedy. A thorough analysis of the mostrecent research makes clear that digital technologiespresent a plethora of options to transformconventional farming practices, maximize resource utilization, and lessen the effects of population expansion and climate change. The results highlight how important it is to incorporate Industry 4.0 technologies—such asblockchain, AI, big data analytics, and wireless sensor networks—into agricultural systems in order to increase output, cut waste, and guarantee food traceability across the supply chain.

The use of digital technology in agriculture is mostlydriven by key players, such as governments, research organizations, private firms, and agricultural institutions. To build an environment that supports innovation and technological dissemination at allstages of the agricultural value chain, cooperation, investments, and policy support are necessary.

In conclusion, it can be seen that how revolutionary digital technology can be very much advantageous for the agricultural industry in assuring food security,advance sustainability, resilience, and equitablegrowth in the agriculture sector by utilizing precisionfarming, data-driven insights, and smart agriculturalmethods. It is crucial that we continue to be aware ofthe various needs and goals of farmers as we navigatethe complexities of the digital age.

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