



Implementation of Digital Twin Technology for predictive Crop Disease Monitoring

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Abstract. With the population of animals and humans cultivating rates of crops and plants are increasing. Thus, demand also increases. The science of agriculture innovates several techniques to improve the cultivating sector to improve production. When it comes to production there is harvesting losses are considered. During cultivating farmers face problems like diseases and insects which aid production rate decreases and increase the rate of those crops. For several years science agriculture tried to make a quick medication system for detecting plant disease. For this problem, we produce a solution that features a combination of hardware and software-created models that help to predict diseases. Crops like potatoes and tomatoes are an everyday need in Indian homes. From few years rate of potato and tomato are goes high. To prevent these losses and deal with this problem this paper uses the digital twin concept which creates a replica of a farm and which works with Yolo to cure.

Keywords: Machine-learning, CNN, Digital-Twin, precision farming, early prediction, Azure platform.

1 Introduction

Agricultural activities have been part and parcel of the culture of India for thousands of years. Agriculture is not just a source of survival but is also a closely integral part of their culture, tradition, and way of life. India is among the largest producers in the world, and the sector is involved with more than 50% of the country's work force. However, despite its importance, Indian agriculture is mostly encountered with many problems that include poor productivity, low exposure towards modern technologies and infrastructural deficits, and unpredictable weather conditions. Smart agriculture, which produces a high yield with optimal usage of resources has become a need all

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S. Bhalerao et al. (eds.), *Proceedings of the International Conference on Recent Advancement and Modernization in Sustainable Intelligent Technologies & Applications (RAMSITA-2025)*, Advances in Intelligent Systems Research 192,

https://doi.org/10.2991/978-94-6463-716-8_49

over the world due to a rise in population and scarcity and increasing cost of resources such as water, fuel, and fertilizers. According to the latest studies it is expected that increase in population will raise the demand of increase crop production by 25-70 % to meet the global food needs according to the analysts. [1] To overcome these challenges, the Indian government and private sectors are now moving towards digital farming. Such advanced technologies in the field of agriculture should be used more comprehensively in the areas where the agriculture sector constitutes a significant portion of the economy, and the rate of increase of population is sustained so that the balance between supply and demand for food gets disturbed .An even more interesting term is the Digital Twin, defined as a digital replica of physical assets, processes, and systems that can be applied for various purposes. In turn, the digital twin conceptual model contains three major parts: a) the real-world products in real space, virtual products in virtual space, and the links of data and information that bind the virtual and real products together. DT reflects its behaviour and statements over its life cycle in a virtual space. In the Industry 4.0 framework, related aspects may be addressed using adjacent terms like Non-physical Systems (CPS). In many areas including product development, manufacturing, supply chains and even in agriculture, CPS can be applied based on the thought of the digital twin. DT promises the best physical response via real-time digital awareness for smart farm tasks. The Internet of Things, as realized, is the epitome of making connectivity ubiquitous. Thus, most of the processes in the smart farm can be tracked in real time not just agricultural product but also tasks, weather condition, satellite information and supply chain process etc. In the IoT vision, therefore, very high level of interoperability must be attained not only on the communication level but also on service and even knowledge levels along various platforms established on a common grounding. Digital Twin Smart Farm (DTSF) changes everything-from soil, water, air, and fertilizers to the farm building, LED illumination, digital technology, and data analytics. Thus, DT eradicates fundamental restrictions based on place, time, context, and human touch. A DT architecture is a physical object within real space, a digital representation of that object in virtual space and the bridge between the virtual and real spaces for the transfer of data and information. In bringing this research, the main contributions and significance narrowed down to suggesting the concept of a digital twin smart farm architecture and bringing it into life through implementation in the laboratory environment from a practical standpoint. It thus demonstrates how the smart farm architecture can be realized based on the technology of digital twin. The approach is also implemented in the real environment of a smart farm that demonstrates the possibility of a case of commercial success [2].

2 Related Study

Traditional Agriculture is nothing but traditional Knowledge passed down from generation to generation. As we know climate change occurs in the early years and affects every industry including Agriculture. In this condition, farmers face problems harvesting which raises year by year. Harvesting season factors like environmental changes, diseases, and lack of water can lead to the loss of the entire yield of the farm. To ensure this condition digital twin technology introduces the technique which integrates with IoT. This helps to give information about diseases occurrence in an earlier stage of its growth to prevent the destruction of crops and helps achieve a low level of loss in the post-harvesting period to get maximum yield. can significantly reduce the impact of climate variability on agriculture. Crops like Tomatoes and potatoes which have higher rates these days can be reduced with this technology. The above diagram shows harvesting losses from the Indian Journal 2022. The below diagram (Fig. 1) shows harvesting losses from the Indian Journal 2022. [3]

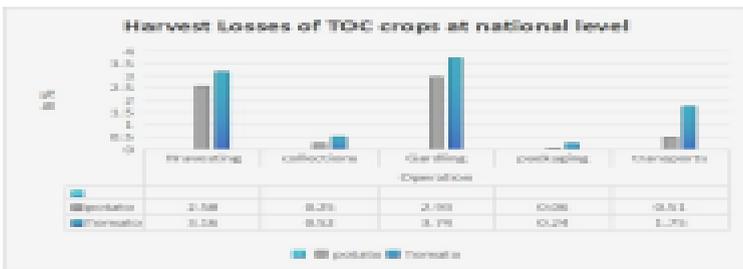


Fig. 1. Graph of loss of harvesting of crops in 2020

In this case, the use of this technology is able to alleviate such losses dramatically, in such a way that the crops are able to return to the field during cultivation by improving grower management from planting to harvest. Rafel Gomes Alves and his teammates [4] proposed a system for crop monitoring using digital twin technology in which they delved into IoT system integration to connect different assets and parameters that have an impact on the farm's behaviour. Its crucial feature which makes farmers make better decisions and decreases effects on water, soil resources and land. Youl-Kim and his teammate Taioun Kim [5] studied the concept of digital twins in agriculture, in which they proposed that digital twins ease monitoring and even decision-making in framing, and they studied prototypes for monitoring crop growth while the purpose of their use in specific branches of different areas like the dairy sector, etc., and integrated them. This transforms the tradition of farming into new dimensions. They delved into a DT model that has been implemented at the laboratory level, in which they checked all aspects of the crops at several levels with the help of sensors [6] Pelin-Angin and his team proposed the digital twin architecture for crop disease with the help of a machine learning algorithm. They used the CNN algorithm and achieved 0.95 accuracy for the detection of crop defects. They proposed DT technology for exciting research on IOT sustainable smart agriculture. By developing a framework that represents a farm with constant monitoring of soil moisture, water level, crop disease detection, and the recommendation of fertilizer treatment. while they focused on internet connectionless /framework. as they highlighted vital considerations in monitoring and crop detection.Devvrat Verma and his team propose [7] new aspects that analyze images and recognize patterns, and

research recently created new techniques. using only images of plant leaves, the deep CNN model that has been proposed can accurately categorize 38 varieties of healthy and unhealthy plants

3 Factors

After gathering related studies or methods, we have focused more on the climates, soil nature, and types of diseases to get a compressive analysis of causes as per the system; the diseases are not only due to water or pollution; besides, we study accordingly the main roots of growth essential to crops, specifically tomato and potato climate and soil natures, which are the basics of research; and in factors, there is a study of Indian climate and soil nature, which are required for crop health as per its monitoring system.

3.1 Suitable soil for growing potatoes:

The potato cannot be grown on alkaline and saline soils other than these two types of soils it can be grown on any kind of soils. Naturally, loose soils are preferred because they provide least resistance to the enlargement of tubers [8] The soil which have pH of about 5- 6 is ideal for the growth of potatoes (Fig. 2). Soil rich in organic matter such as sandy and loamy soils are suitable for the cultivation of potato crops. Potatoes require moderately cool climate for its growth, its growth is at peak when the temperature ranges between 20°C to 24°C and the tubers grows its best at 20°C. During summer season potatoes are grown in hills and during winter it is grown in subtropical area. It can also be grown at the altitude of 3000m above sea level, heavy clay soils quality can be enhanced by adding sharp sand and lots of primal matter in autumn of the year thus soil mixture can be uncovered to frost which will break up the soil structure and make it simpler to work with. The nutrients needs of potatoes are quite tremendous and the demand of fertilizer and organic compost are considered important to obtain budgeted and high yields. Green manuring is useful in light soil and places where organic manure is not present. The fertilizer dose varies depending upon the soil fertility, climate, and variety length of growing season.



Fig.2 Soil suitable for potato and tomato cultivation

3.2 Soil suitable for tomato cultivation:

Tomatoes are best to cultivate in loam or sandy soil. Solid soil structure is essential to permit proper water and airflow supply into the soil, which could elevate plant development. The pH ranges between 6.2 to 6.8 is required by tomatoes for best nutrients absorption and tomatoes need continuous supply of minimal and major plant nutrients. Fertilizer are added into soil 2 weeks prior the planting. Surplus amount of nitrogen can result in plants with luxuriant, vigorous foliage but with small fruit production.

3.3 Late blight disease:

Phytophthora Infestans the pathogen was first described by M.J Berkeley and named it Phytophthora infestans by Anton De Bary in the 1870s. It is member of the oomycetes; they are true fungi but closely related to brown algae. It reproduces Sexually as well as Asexually. In Asexual reproduction Phytophthora infestans produces Sporangia on the plant. In cool or wet condition zoospore will form and emerge from the sporangia after about two hours. In Sexual reproduction two mates comes in contact, Fusion of the two nuclei in the oogonium, a thick-walled diploid spore is formed. Phytophthora infestans, which causes dark lesions on leaves and tubers. [9]

3.3.1 Symptom and Control:

Disease infect all parts of plant like leaves, stem, and tubers. initially water-soaked lesion develops on tip and margin of leaves, it increases rapidly. there is brown/black or pale green spot-on leaves. these area become large brownish/ black lesion. Stem become weak and collapse causing death of above lesion. tomato or potato develop irregular brown to purplish skin, greasy spot inside the fruit, in tomato there is concentric ring developed on fruit. Farmers used pesticides(fungicides) to control the late blight disease .apply copper-based fungicides before dry weather folice sprays of organic coating agent can also prevent the infection some gardeners prefer chemical fungicides, the best of which for tomato is chlorothalonil. Bordeaux mix((fungicide) is effective to control the infection. No fungicides are proved completely resistant to the disease. resistant varieties can be used. [9]

3.4 Early Blight Disease:

Early blight disease caused by *Alternaria solani*(fungi) belonging to the class Deuteromycetes. It reproduces Asexually, Sexual reproduction is not seen in

Alternaria solani. It affects stems, leaves, tomato, and potato itself. It occurs in cold as well as hot weather. It appears on new plant mostly. The mycelium of the fungus consists of septate and sparsely branched hyphae, which affect the plant. [10]

3.4.1 Symptom and Control - It occurs on leaf, stem, foliage, fruit of tomato and leaf, stem, foliage, and tuber of potato. There are small brown spots on leaf which turns into enlarge concentric ring giving them bull's eye pattern it can affect tomato fruit when it attacks on calyx and stem. The potato tuber sunken lesion, which is often surrounded by purple border, the tuber tissue is leathery or corky with a brown discoloration. Farmers used pesticides(fungicides) to control the early blight disease. There are many fungicides present in the market to control early blight (Fig. 3). Some of the chemical fungicides are azoxystrobin, pyraclostrobin, trifloxystrobin and fenamidone. The protectant fungicides such as mancozeb and chlorothalonil. The biological fungicides used are *Pseudomonas* – Fluorescence, *P. putida* and *P. cepacia*. *Trichoderma* and *Bacillus* spp. are also used.



Fig. 3 Early blight and late blight in potato and tomato, respectively.

3.5 Climate suitable for Potato cultivation:

Potato growth is at peak when the temperature ranges between 20°C to 24°C and the tubers grows its best at 20°C. During summer season potatoes are grown in hills and during winter it is grown in subtropical area. In the Indo-Gangetic Plain the potato crop duration has decreased due to climate change. There is increase in evapotranspiration while the water use efficiency for potato growth is projected to decrease in future climates as outcome of low threshold temperatures for decrease in water use efficiency and growth than the evapotranspiration. Results shows that upper threshold for water use efficiency decline is 15 °C at the same time that for evapotranspiration is 23 °C. The best possible temperature for tuber growth is 17 °C and for that reason the reduction in water use efficiency in upcoming climate is perceivable. Potato yields are predicted to decline by 2.5% in 2020(2010-2039), 6% in 2050(2040-2069) and 11% 2080(2070-2099) time intervals. The only option which may result in yield gains is change in plantation timing. [11]

3.6 Climate suitable for Tomato cultivation:

Tomato growth is at peak when the temperature ranges between 22°C to 29°C Temperature bounds the yield and range of tomato crop. High temperature condition is frequently prevailing during growing season in tropical region. Climate trends in

tomato growing area indicates that temperature is rising and severity and occurrence of above-ideal temperature will elevate in future. Tomatoes are strongly affected by temperature and other environmental factors also effects its production. It firstly effects the photosynthetic operation of higher plants. High temperature disturbs the biochemical reaction basics for normal cell function in the crop. High temperature can cause significant reduction in tomato productivity and lower quality fruits. Water availability is supposed to be extremely sensitive to climate change and acute water stress circumstances will affect production of tomato. [12]

4 Research Methodology

The DT concept has been incorporated into smart agriculture at both the laboratory and field levels. All field crops need soil, light (sunlight), warmth, air, water, and nutrients to grow. Soil provides stability to plants and stores water and nutrients that plants can absorb through their roots. Light (sunlight) provides the energy plants need to grow. Air allows plants to “breathe.” Water provides moisture and nutrients. Components in Proposed System: In the proposed system digital twin technology is based to develop a farm model by integration of sensor within field. Crucial 4 components. Anything more or less than this would cause failure.

4.1 IoT:

IoT includes integrated sensors and Raspberry Pi controller. In the proposed system, we have used many sensors such as soil moisture, temperature, humidity, water level, nutrients, camera module and others connected to Raspberry controller. The system is connected to the agricultural fields and monitors every aspect of the crop according to the standards. To monitor the health of the crops, we need to monitor the following: Soil moisture sensor to measure the moisture in the soil, Water level sensor to control the amount of water needed, Humidity sensor to monitor the moisture in the soil or around the crop, Nutrient sensor Control, camera module to capture images, carbon dioxide sensor and pH sensor to check the copy to make sure the pH percentage in the soil is correct.

4.2 The Azure platform:

has An IoT hub This is automatically collects and responds to data in the cloud powered by azure. This also facilitates the creation and development of digital twins based on digital models of the entire environment, such as housing, agriculture, etc. IoT hub is versatile with it.

4.3 Machine Learning Algorithm:

This algorithm is a supervised machine learning algorithm and thus needs an input dataset as well as an output data set from which it flows, we are using the CNN

algorithm for crop diseases as it is efficient for real-time detection of diseases. Within the framework of the CNN paradigm, there exist several Architecture types to building the algorithms since this model is dependent on an architecture-based assumptions or rather on accuracy and losses as is the case in Google Net, Alex Net, VGG Net. A well- designed implementation of a CNN architecture has several advantages and benefits to the system performance. Research regarding the analysis and comparison of the CNN architectures for the detection of the plant disease has been carried out. [5] This algorithm is a supervised machine learning algorithm and thus needs an input dataset as well as an output data set from which it flows, we are using the CNN algorithm for crop diseases as it is efficient for real-time detection of diseases. In the CNN algorithm, there are several

Table 1. Table of comparison of several Machine algorithms

| Architecture | Accuracy (%) | Loss |
|----------------|--------------|------|
| Baseline[17] | 84.58 | 0.47 |
| Alex-Nete [17] | 91.52 | 0.51 |
| Google-Net[17] | 86.68 | 0.3 |
| VGGNete [17] | 95.24 | 0.26 |
| Yolo | 95.50 | 0.2 |

types of Architecture to construct algorithms as this model has their accuracy and losses on that base from architecture like Google Net, Alex Net, VGG Net, and Yolo (Table 1). The choice of CNN architecture significantly impacts the system's performance. Research comparing CNN architectures for plant disease detection indicates that. Yolo is known as a neural architecture that refers specific design of the neural network(Fig. 4) Which is implemented as the Yolo algorithm. Yolo architecture is a Full CNN that synchronizes images in a single phase which emphasizes real-time detection. It helps specific localization. [14] Rectangular bounding is generated in a box-like structure which targets the portion of the leaf which is affected while the data set has images of crucial parts of plants like stem, leaf, and fruit The green hue for these bounding accumulates the segmentation of leaves and facilitates the visual differentiation of annotated region. Then this segmentation divides the image into smaller species and allocates the labels to identify the diseases and normal leaf region. The presence of green colour bounding boxes on leaves clarifies the segmentation process, emphasizing the accurate detection of ill regions on plants. [15].



Fig. 4 Yolo Architecture and Availability of data set.

4.4 Data Set:

The data set plays a very important in this whole system as it gives DT model training for decision-making processes. Data set Plant-Village has a wide range of 50000+ images of several crops that are healthy and unhealthy. The data set is very important in this whole system as it gives DT model training for decision-making processes. Plant Village data set helps to develop computer vision algorithms for plant disease identification automatically. [15].

5 Architecture

In this system (Fig. 5), there are several layers which are as follows: Physical layers have sensors connected to the field and sensor data travels to the data transmission layer. This layer transmits data to the Azure cloud which is the cloud integration layer. There is a layer called the data management layer which images historical data and real data that comes from sensors. Then this data is pre-processed and analysed in the data preprocessing and analytic layer. this layer is the heart of the proposed system as its analysis images come from the camera module and apply the CNN algorithm which identifies diseases which trained by the dataset. Next is the predictive layer which uses CNN and data to predict. [15] After this layer decision-making layer comes to the image which Generates alerts if it detects the disease. then the last and final layer i.e., the Interaction layer visualize digital twins and data. displays alerts, predictions, and recommendations. the following flowchart shows the architecture of the proposed system. These sensors Gathers real-time data on various aspects such as soil moisture, temperature, humidity, nutrient levels, CO2 concentrations, and crop images. The devices, including Raspberry Pi controllers, act as the interface between the physical environment and the digital system, transmitting data to higher layers for further processing.

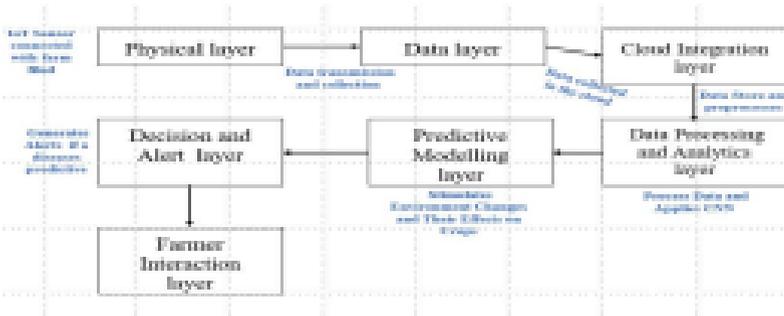


Fig. 5. Flowchart of Proposed System

According to Calvaresi the integration of IoT devices in agriculture is crucial for real-time data collection, which forms the foundation of any smart farming system. These devices enable continuous monitoring of environmental factors that directly influence crop health and yield. The transmission layer is responsible for securely transmitting the data collected by the physical layer to the cloud. This is typically done using wireless communication protocols like Zigbee, LoRa WAN, or Wi-Fi, depending on the range and bandwidth requirements of the farm set-up. [16] This layer also plays a critical role in feeding clean and relevant data to the analytic and predictive layers of the system.

6 Result and Discussion

In the recent agricultural sector, low crop production results from many factors. The most common cause is that plant diseases are widespread and could significantly lower the yields. Luckily, a more recent system has been introduced to consider the early detection of plant diseases. Such a system applies Yolo-like algorithms which come in object detection technology forms. This means that such a system is able to identify diseases on crops and pinpoint exact locations on particular parts of plants. The continuous monitoring capabilities of the system offer more precise real-time detection compared to traditional farming methods (Fig. 6). Early problem detection usually minimizes probabilities of diseases spreading out through the crops, which may add up to elevated losses in harvest. The system also enables farmers to use more resources efficiently by giving them proper information about the quantity of water and fertilizer required for the crops. Therefore, this variation results in an even better approach to managing agricultural inputs. All these advantages notwithstanding, the use of this

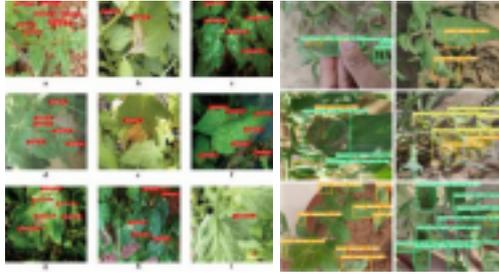


Fig. 6. Results showing detected parts of leaves.

technology is hindered by a few other factors. The process of erecting it usually proves to be very expensive at the onset. We can see the few results above fig 5 This is primarily because of the price of sensors, IoT devices and cloud computing services, as well as the requisite infrastructure for processing data. There's also an issue of security regarding data. As the data held is sensitive and many of them are transferred to and stored on cloud services such as Azure, several concerns arise regarding privacy and data protection issues. In this system, an integrated IoT collects information and forms the virtual representation of crop images at given intervals, which it analyses in order to understand the status of crops in terms of their health and early detection of possible problems. With continuous support from technology, farmers improve their crop management activities and overcome critical challenges of agriculture.

7 Conclusion

The integration of Digital Twin (DT) generation into agriculture affords a transformational method to predictive crop disease tracking. By leverage IoT, device getting to know algorithms, and cloud systems like Azure, Digital Twins offer actual-time insights into crop fitness, permitting early detection and intervention for illnesses together with blight in potatoes and tomatoes. It decreases crop losses, increases production, and ensures improved usage of the aid as well. DT is now not most effectively used effectively in agriculture to help farmers manipulate risks, however, also guarantees sustainable farming. Continued demanding situations from climate trade and escalating demand for meals call for make agriculture stay demanding, yet this holds the important thing for meals systems during the use of superior applied sciences like Digital Twins.

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