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Machine Learning for Soil Moisture Detection: Introduction, Approaches and Challenges

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Abstract

The demand for agricultural is increasing day by day as the population of the world is increasing. So, it becomes necessary for us to increase the production of agricultural products. Traditional ways of agriculture cannot meet such requirements. Nowadays, machine learning based technologies are being used to develop models for agriculture. Machine learning-based applications are very fast and produce high-quality results. It includes recurrent neural networks (RNN), convolution neural networks (CNN) and current state-of-the-art transformer-based models. These technologies have achieved great success in developing models of soil moisture detection, smart greenhouse, disease detection, aerial images, drones and weather forecast. Though, there are various models available in modern agriculture. Still, there is a vacant space in soil moisture detection. Review soil moisture is so important because the soil plays the main role in good production of crops. This chapter aims to introduce various branches of agriculture where machine learning based algorithms are being used. Another important aspect of this chapter is that it presents a review of machine learning based approaches for soil moisture detection. An introduction to machine learning, deep learning and transformer architecture is also explained in this chapter. There are various challenges to implementing AI in agriculture, those challenges are also discussed in this chapter.

Keywords: Soil Moisture Prediction, Machine Learning in Agriculture, Deep Learning Models, Remote Sensing, Smart Farming

INTRODUCTION

The world population is 8045 million in 2023 as said by the United Nations Population Fund (UNFPA)'s website [1, 2]. UNFPA published data on the Indian population in 2023 where they wrote, India at the top position with 142.86 crore population in the world where China at rank 2. This report was published by the Indian Express newspaper in 2023 [3, 4]. Food is the most important for human to live life. So, as the population is increasing, demand for food is also increasing. Meeting the demand for food remains a big challenge for every country. The traditional way of agriculture is unable to fulfill such requirements. So, the world thought about technological agriculture.

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Nowadays, machine learning based technologies are being used to develop models for agriculture to meet such challenges of food. Machine learning based agriculture is known as smart agriculture. It includes digital technologies such as IoT and AI based applications. Such types of applications can be developed with recurrent neural networks (RNN), convolutional neural networks and current state-of-the-art transformer-based models [5]. These technologies have achieved great success for developing models of soil moisture detection, smart greenhouses, disease detection, aerial images, drones and weather forecasts. There are various types of sensors that help the farmers to do smart agriculture.

Though there are various models available in modern agriculture there is a vacant space in soil moisture detection [6]. The farmers must focus on the soil as it is the main component for good production of crops. Hybrid varieties of crops are used by farmers all over the world to increase production. On the other hand, several pesticides are used by farmers for maximum production. Such types of experiments are spoiling the quality of soil. This chapter aims to introduce various branches of agriculture where machine learning based algorithms are being used. Another important aspect of this chapter is that it presents a review of machine learning based approaches for soil moisture detection. An introduction to machine learning, deep learning and transformer architecture is also explained in this chapter. There are various challenges to implementing AI in agriculture, those challenges are also discussed in this chapter.

BACKGROUND

There is a wide range of algorithms in machine learning, those may be deep learning based or machine learning based. So, before creating a model in machine learning, the developers need to know the basics of machine learning. An introduction to Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL) is presented in this section.

Artificial Intelligence (AI)

Alan Turing wrote his seminal work in 1950 under the title "Computing Machinery and Intelligence" that has become the foundational text of Artificial Intelligence research. The developer Francois Chollet at Google who created the Keras library defined AI using this statement: “The effect of automating intellectual tasks normally performed by humans” [7]. Artificial Intelligence exists within computer science to create machines able to imitate thinking processes of humans. AI machines learn from big data which constitutes their basic terminology for acquisition of knowledge. The establishment of AI models requires extensive volume of available data. AI works in different agricultural sectors including weather prediction technologies alongside

Machine Learning (ML)

As shown in figure 1, ML is a part of AI [7] which is used to solve a particular agriculture-related problem without explicit programming. These ML based models can learn the rules from past data and work on real-time problems. There is a particular pattern in input data that helps such a model to make predictions. So, large data is very useful for such models to make decisions and we can say more data means better results. Such types of predictions can be made from text data as well as images. The various types of images of land are used for the detection of soil moisture. Here, drones and even GPS help the farmers for taking images.

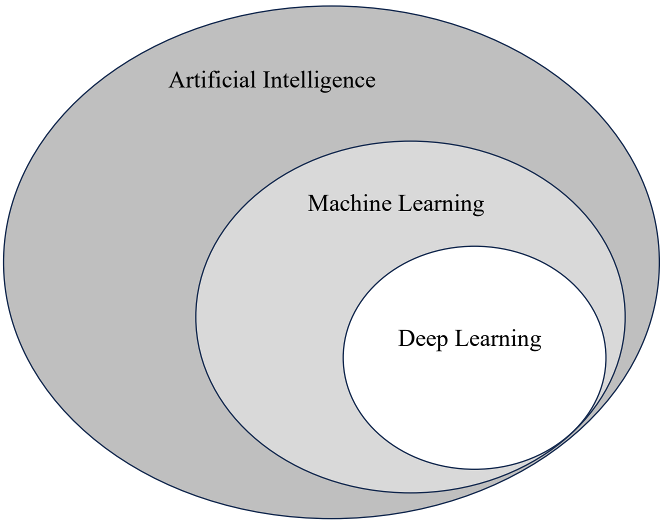

Figure 1. Artificial Intelligence, Machine Learning, Deep Learning.

All over the world, data is increasing in every field and that data is helpful for the development of different models. Financial, health, agriculture, and education are the different branches where these models are doing great work. Due to the trust in these models, a lot of work has been done in agriculture using machine learning.

Deep Learning (DL)

Deep Learning is a part of machine learning and we can say all the DL models are Machine Learning models. As shown in the following diagram, machine learning models use layered architecture [8–10]. This architecture is very similar to the human brain. The first layer is an input layer and the last layer is an output layer. The input goes through the input layer to the model and output at the output layer. Between the input and output layers, there are multiple hidden layers. The number of layers in the model depends upon the problem on which we are working. Figure 2

As already said in the previous section, this architecture performs better on large data. This data is then passed to the model (multilayer) for extracting features. This data shares weights and biases continuously to improve the results [10]. Such a type of example is shown in Figure 3.

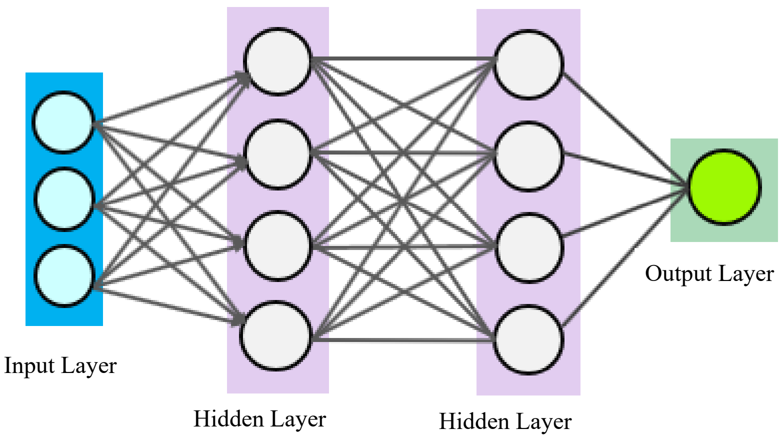

Figure 2. Neural Network [10].

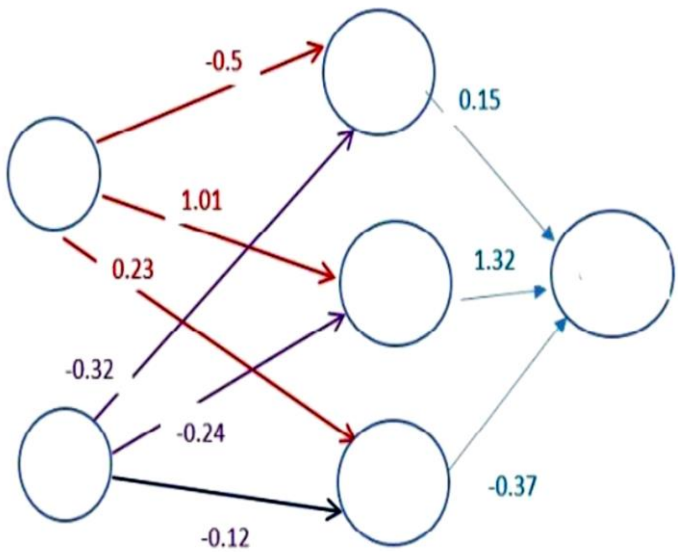

Figure 3. Interconnected Layers in Neural Network [11].

Transformer Model

Attention is an important topic in deep learning which allows the deep learning models to focus on important information so that the prediction can be as per the requirements. The basic RNN is unable to pay attention to important information. So, an attention mechanism is used to pay attention to the important information. This is an encoder-decoder architecture that includes multiple layers of encoder and decoder as shown in the following Figure 4. Each encoder is made of two sublayers i.e. Multi-Head Attention and Feed Forward Network layer. This is the architecture first presented in the paper [24].

MACHINE LEARNING BASED BRANCHES OF AGRICULTURE

Sensors

To measure the crops, soil and images, various types of sensors are used in agriculture. These sensors can detect moisture in soil as well as its quality. These sensors can also tell the need for water in the soil. So, farmers can give water to their crops at adequate time. This affects a lot on the production of crops. The sensors can detect moisture in crops at the time of cultivation. It suggests the farmers an appropriate time for the selling of their crops.

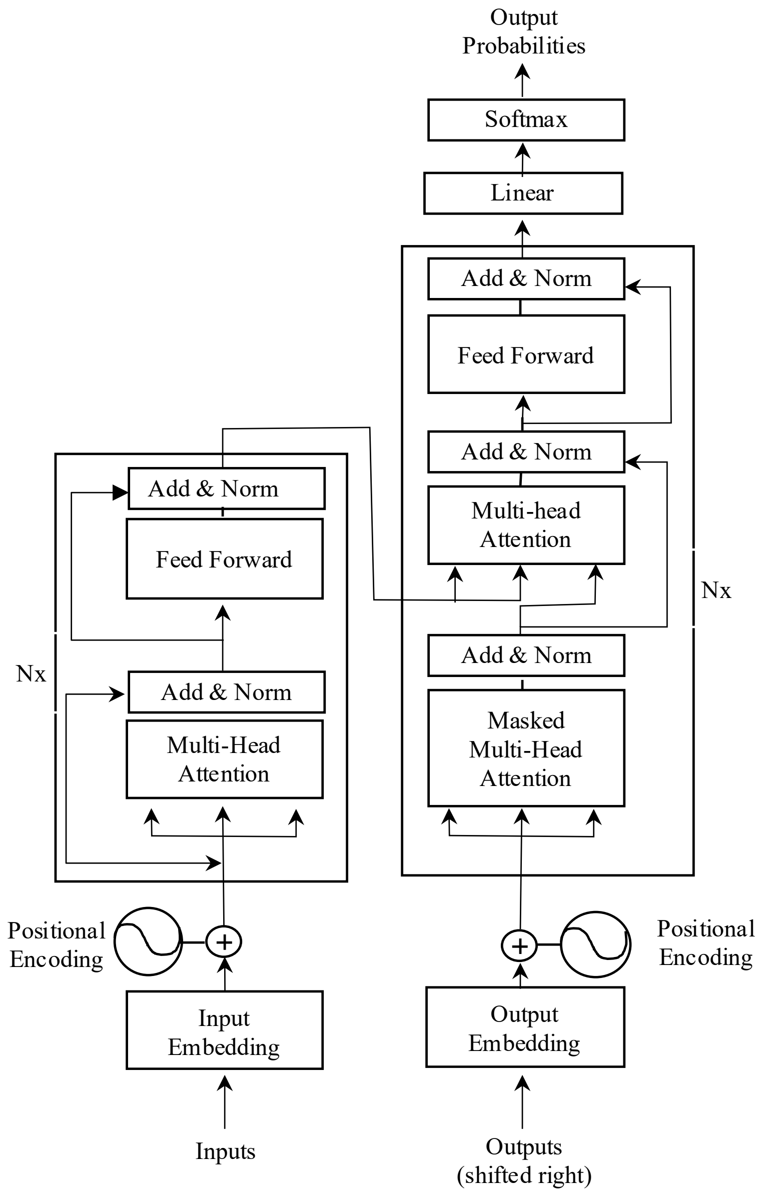

Figure 4. Transformer Model [24].

Water sensors can detect the quality of water. Whether water is required or not, it is also able to be determined using sensors. Greenhouse farming is an example of such a system. Some other sensors useful in agriculture are optical, electrochemical, location and airflow sensors. The data gathered by sensors is then transformed into an electrical signal. This transformation of data can be processed, and stored for further operations. [12–14].

Smart Greenhouse

The smart greenhouse is a type of agriculture that uses IoT based technologies. It is basically to provide an adaptable environment for agriculture, especially vegetables and fruits. It uses different types of sensors to control temperature and humidity. It also protects the crops from unwanted rainfall [12].

Disease Detection

Disease detection is a hot area in agriculture because it affects the production of crops a lot. This detection can be of two types; a traditional method where features have been extracted from the crops and then classification has been done. This approach was used widely in past research as it was the easiest method. It included features such as texture, shape and color and brightness, age of the crop. After this, only a classifier was applied to determine the disease. The drawback of this approach is that it cannot handle high-definition images, is unable to recognize features from low-quality images and is difficult to understand complex images. At the early stage of the disease, it was unable to find the appropriate disease [16].

The advancement of machine learning models in agriculture solved the above issues for disease detection. Convolutional Neural Networks (CNNs), and Deep Belief Networks (DBNs) are the current techniques used for disease detection. These approaches work on a large set of images to detect diseases in crops. Most of the disease detection models are related to specific plants and diseases also [16]. After these approaches, transformer based approach is also available for the detection of diseases within plants [17].

Aerial Images

DL based models require a large data set of images that prepare results from images of crops. So, the collection of such images in the field is a big challenge. Aerial image is where Geographic Information Systems (GIS), GPS (Global Positioning System) and satellite imaging technologies are used for collecting such images [12]. These tools provide good-quality images because the performance of DL models varies with the size and quality of data. As we know the change in weather also affects the growth of crops. It becomes necessary to take random images of crops without physical visits to the field. The above-mentioned tools help a lot in such situations.

Drones

The drones are Unmanned Aerial Vehicles (UAV) with small or medium size and can controlled remotely. These are similar to aircraft which can fly in the air. Drones are very helpful in agriculture as they can collect aerial images, spray pesticides, and help in irrigation assessment and soil monitoring [12].

Weather Forecast

In agriculture, weather is an important factor as it affects the crops a lot. The change in weather also affects the growth and production of crops. At the time of sowing the crop, the weather is taken care of and similarly, the weather is also taken care of while harvesting the crop. Timely rain is good for the crop but untimely rain damages the crops. So, weather forecast helps the farmers to know the condition of the weather in advance.

Due to the advancement of deep learning in every field, researchers have applied it in weather forecasting. A lot of work has been done in this area and is producing good results [18].

Robots

This is another technology that is used in different areas of the world such as mining, transport, manufacturing, scientific labs, restaurants and space. due to their efficiency, nowadays robots are also used in agriculture [12].

SOIL MOISTURE

Soil is a natural resource that is the outer part of the earth. It is required for the growth of any land plant. Soil is sometimes referred to as the 'skin of the earth'. Soils develop over time under the influence of chemical, physical and biological processes. It consists of minerals and organic matter in the earth]19]. Its quality is determined by soil pH and Gradiation level. The quality of soil can also be recognized from the production of the crops [21].

Soil moisture is a vital component in regulating water and energy circulation between land and atmosphere [15, 20]. The change in climate affects soil moisture in the field. This climate change is related to changes in temperature and precipitation [20]. Soil moisture is important for crops because it means the availability of water in the soil. To determine the soil moisture is also important for better production in agriculture.

Soil Moisture Detection

As said by the authors in [20], soil is a natural resource whose quality is determined by soil pH and Gradiation level. The quality of soil can also be recognized from the production of the crops [20]. Image processing is another important topic that is widely used in different fields. The authors in [20] used image processing for detecting moisture in soil. They have used different image processing techniques for determining the type of soil, color of soil and pH. As the study told, the pH range defines neutral, acidic or basic types of soil. They have used k-means clustering and kd-tree algorithms for detecting the color of the soil.

Soil moisture is not only required for better production of crops, but this information is also necessary for different hydrologic and climate applications. So this information can be collected from satellite images or model simulation [21]. Satellite images provide many variations in the dataset. The authors in [21] presented data on soil moisture using machine learning techniques which are publicly present. They have trained their dataset with in-situ measurements, SoMo ml. They have applied LSTM on data which they collected from different 1000 stations all over the world from 2000 to 2019. After this, the authors compared their data with other available datasets of soil moisture.

Another work for soil moisture was at the root level which was implemented by the authors in [22]. They named it Root Zone Soil Moisture Detection. The authors collected data with sensors from different regions. The authors in [23] worked with Google Earth Engine to develop a soil moisture model. They also launched a cloud-based Python API for collecting data for future use.

The authors in [24] presented a brief introduction to different machine learning-based algorithms for soil moisture detection. In this study, the authors discussed those studies which used sensors for doing this task. First, they discussed PTFs which are used for detecting soil properties. PTFs help to find the relationship between soil properties that are hidden or cannot be detected easily. In the second phase, the authors discussed various methods for soil moisture detection. The sensors are important as discussed in section 1.1. The authors talked about sensors also in their study. the radiometer, scatter meter, and SAR, on-board air-borne or space-borne platforms, operating in microwave waveband, are used to retrieve soil moisture content [24].

The machine learning techniques are very fast and are based on the quality of data. The work in [25] used satellite-based Synthetic Aperture Radar (SAR). There is a big difference between soil moisture values when information is collected from ground data and satellite. Support vector regression is further applied to fill that gap. The short-range and wideband radar sensor operated in the range of 3-10 GHz in the work of [25]. The authors used dielectric constant and regression-based models for detecting water in soil.

Soil moisture is an important aspect of a natural cycle. It is a challenging task to determine soil moisture as the soil has multiple variations. The authors applied a deep learning approach for solving the problem in [26]. They have applied 10 different deep learning models to detect moisture. Out of ten, three are the basic structures for extracting features and the remaining seven are hybrid models. The authors in the paper [26] used hybrid models for the first time. As the study said, LSTM with an attention mechanism and generative adversarial network-based is better than LSTM.

LSTM is an RNN-based architecture to process sequence data. It has been widely used in soil moisture or related applications. So, its capacity to learn long-term dependencies, the authors in [26] used this architecture to develop another dataset of soil moisture. They set the parameters as 128 hidden units, one layer of LSTM and one dense layer and the dropout rate was 0.5.

The latest study for soil moisture detection is presented in the paper [27]. The authors applied an attention mechanism in their work. As discussed in Section 2, there are different layers in deep learning architecture, the authors applied those layers to developing a soil moisture detection model. The authors used LSTM layers for detecting short-long term dependencies from the time series soil moisture data. Other than LSTM layers, they used the attention layer for learning discriminative information. The authors further applied a Generic Algorithm (GA) for improving predictions.

CHALLENGES FOR IMPLEMENTING AI IN AGRICULTURE

1. AI is a technical branch and it requires knowledge about the working of such technologies. When the farmers want to use such advanced systems in agriculture, they have to be aware such technologies. The farmers are less experienced with practicals of AI based Agriculture.
2. The farmers should participate in discussions and seminars. But the farmers are not ready for this. They only follow their past experiences. When we talk about a country like India, it becomes more challenging because here farmers are less educated [12].
3. Another challenge is to fulfill the infrastructure requirements for implementing machine learning models in the field [29].
4. Security is another challenge when farmers are using such advanced technological systems in the field.
5. It is a big challenge to implement AI in agriculture in India. We can discuss a simple case study: most of the AI based applications are very costly. On the other hand, there are more farmers with less agricultural land in India. For small farmers, it is difficult to adopt such advanced technologies.

CONCLUSION AND FUTURE WORK

This chapter introduced that the increase in population has to face food related problems. One of the methods to increase food production to adopt machine learning based applications in agriculture. Machine learning based applications are very fast in learning as well as training for producing high quality results. It includes recurrent neural networks (RNN), convolution neural networks (CNN) and current state-of-the-art transformer-based models. This chapter presented different technologies that are being used in agriculture and achieved great success for developing models of soil moisture detection, smart greenhouse, disease detection, aerial images, drones and weather forecast. This chapter introduced the soil moisture detection approaches that plays the main role for good production of crops. An introduction to machine learning, deep learning and transformer architecture is also explained in this chapter. There are various challenges for implementing AI in agriculture, some of the challenges are also discussed in this chapter.

Agriculture is a wide area where AI based applications are used. Different regions share different climate conditions. At the time of training, it is difficult for the models to handle important information. At that time, it is required to distinguish between elements between different regions.

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