IoT and Cloud based Smart Agriculture Framework to Improve Crop Yield meeting World's Food Needs

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Abstract
Internet of things (IoT) provide connectivity of all physical objects and devices being used in daily life with each other and with systems for the purpose of data exchange and storage. Another important use of such data exchange is to enable better and error-free decision making. IoT is being used these days in various fields, "Agriculture" is one of them. Modern methods are being adopted in the field of farming and so is the field of smart farming being developed. Huge volumes of data are generated from the farms, which remains unexplored. This paper suggests suitable sensors deployment for better crop yield and a framework, which can be adapted by farmers to enhance crop production in order to earn better revenue and also meet the demands of worlds food needs.

Keywords: *Cloud based; Deep Learning; Internet of Things; IoT in Agriculture; Smart Farming;*

1. Introduction

The term "Internet of things", usually called IoT encompasses many aspects of the Internet and the World Wide Web. Numerous devices in count capable of sensing data have been placed at various locations with distinct identifications. The IoT enrichment has revolutionized the future of technologies being currently used resulting in the development of a new class of smart and intelligent applications and software enabled services [1]. It enables all objects in use to be identified, sensed, networked and capable of processing data, so they can communicate with each other and also with other devices and services. These IoT enabled devices are supposed to be pervasive, ubiquitous, and context-aware and also possess ambient intelligence [2]. Massive data is being generated by IoT and is considered as increasing trade worth. Data mining techniques are applied to the data to dig-out unseen information from the data [3]. Work is being done to develop dedicated, minute, little power-driven interconnecting instruments to be used in IoT projects and to support the joining of implanted systems containing complicated sensors and actuators configured with the cloud [4]. Deep learning is a subfield of machine learning. It is also known as deep structured learning or hierarchical learning.

It is based on learning data representations. It enables us to imitate the working of the human brain in data processing and pattern creation to be used for making decisions. Applications include driverless cars to speech recognition etc. making impossible to possible now. Automatic systems for emotion recognition are being built for the prediction of human emotions [5] improving the classification accuracy in "Feature Selection Methods". Still many of these methods capture linear relationships between features. Deep learning techniques can be used to overcome earlier weaknesses by application of complex non-linear features. It was proved that higher-order non-linear relationships are better for emotion recognition. Deep learning techniques belong to a class of machine learning algorithms capable of accepting raw inputs into intermediate layers giving better results in different domains. They have shown progress in the domains of biology and medicine to solve issues in these domains. Deep learning supports solving patient classification, fundamental biological processes as well as treatment of patients.

Deep learning is revolutionizing the biomedical field and helped in speeding up human investigation. Interpretation of neural network models prediction to input features, conversion of models to testable hypothesis is still difficult. Health records availability is also limited due to various legal and privacy constraints [6]. Multi-label (ML) image learning concept, which includes assigning different labels to images in a dataset, is a recent concept. Image classification is the labeling of images with various class labels. Deep Convolutional Neural Network (CNN) and Hybrid CNN are proposed for large scale ML datasets. Deep Learning Network (DLN) is proposed for syndrome diagnosis. DLN training is done in two parts pre-training and discriminating fine-tuning. DLN has outperformed existing methods in terms of accuracy with less number of features [7]. IoT and deep learning are being used together and this is the beginning of a new revolution for the entire world. Intelligent IoT is a new concept being introduced after the evolution of IoT to enable us take decisions on-time and avoid major mishaps as well as producing better results.

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2. Technology Study and Literature Review

IoT sensors and actuators are blended in the environment and share information about every parameter hence making it useful. The development of Web 3.0 enables the inclusion of cloud structure also [8].

A new concept of digital orchard has evolved replacing older methods of disease and pest control by early warning systems to result in a better planting environment.

The “Alerting Systems” named “Convolutional Neural Network (CNN)” identifies the images of melons, apple skin etc. to monitor and control the growth of various fruits are being devised [9].

An increase in the world’s population requires precision and optimization in agriculture field.

Fresh edible food items are needed in huge quantities and hence IoT become important to do smart and intelligent agriculture.

Smart mobiles and IoT devices enable farmers to learn continuously from farms. The Internet has enabled farmers to build cloud-based applications to do farming keeping all factors under consideration [10].

Segregation of waste is also an important issue as it may result in health hazards and environmental issues. Segregation of waste and storage accordingly to be utilized is necessary [11].

Machine learning can be applied to big data extracted via IoT devices to identify patterns and hidden features in very complex data sets [12].

Another research was done to retrieve agricultural information including image-based plant phenol-typing, harvest quality data and location information using cameras in greenhouse [13].

Another study was done to classify fruits using deep learning, neural networks layers were used and clear fruit images were compared with obtained images for classification [14].

Huge databases of plant species are available, which has solved the problem of plant identification or plant disease recognition by image processing, extracting identical features and classification. Weather forecasting, smart methods of irrigation by the use of modern computational methods can be used [15].

Another study identifies the use of IoT including Radio Frequency Identification (RFID), Wireless Sensor Network (WSN) and Global Positioning System (GPS) for the management of farms and also greenhouses.

Agricultural products are now safer and of improved quality and also speed of operations has become faster reducing the cost of labor [16].

Deep learning has played a vital role in speech recognition, computer vision, object recognition and NLP. It enables users to analyze data and hence now being used in agriculture as well.

Machine learning algorithms can be applied to resolve food production challenges. Deep learning has proved better accuracy outperforming older methods [17].

Data mining techniques are used for classification and assist in prediction of crop diseases to prevent the loss in production.

Classifier techniques were used in this study such as “Decision Tree”, “Random Forest”, “Neural Networks”,

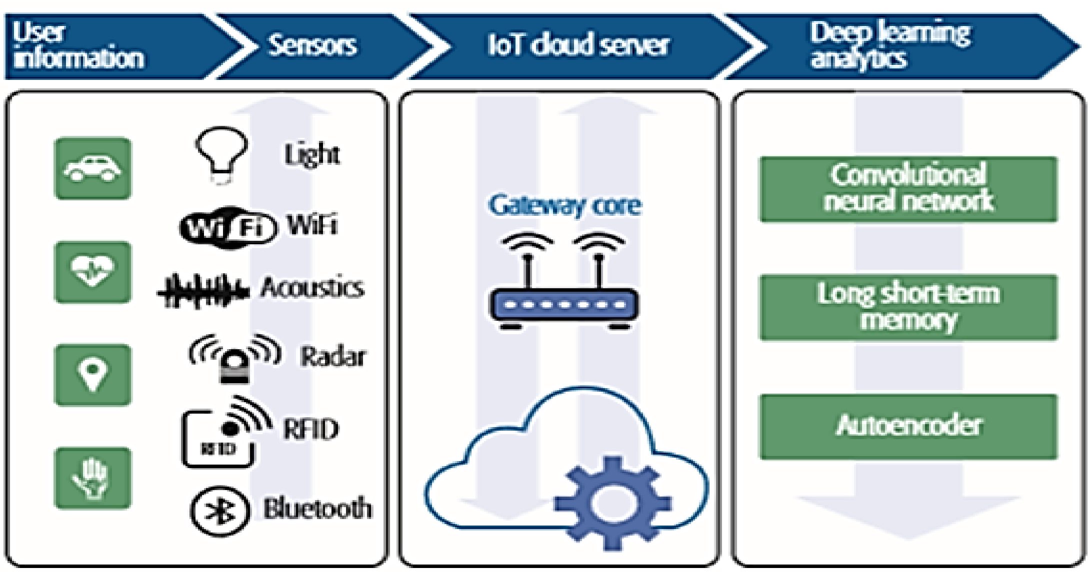

Fig. 1. The layered architecture for RF sensing in the IoT Ref [26]

"Naïve Bayes", "Support Vector Machine (SVM)" and "K-Nearest Neighbor Algorithm (KNN)" were analyzed. A hybrid of these techniques was suggested for better results [18].

Autonomous vehicles can be connected to achieve automated operations with minimum supervision resulting in human health betterment and reduce labor costs [19].

Precision agriculture is another methodology used to gain better productivity and lower costs with high yields. Water used in irrigation can be automated as well as automated animal monitoring is analyzed [20].

Work was also done using a low cost CPU for the prediction of outdoor temperature in IoT based agriculture. Watering schedule, precautionary measures can be taken from frost damages as well as management of greenhouses can be done [21].

A study was done in India for selection of crops suiting soil for maximum yield. The selection of certain crops for specific soil is an art. A specific recommender system model was developed to achieve this goal [22].

Another study used Deep Learning concepts in agriculture in Costa Rica to employ CNN to meet food challenges. CNN showed high performance with precision, but the quality of data set is also important [23].

A systems "Smart Asset Management System (SAMS)" have been developed to monitor soil condition and status for variable fertilizer application.

The experiment was performed on rice crops, a smart rice planter was used. Also fertilizer applicator and yield monitoring harvester were used. Improved fertilizer cut and harvest efficiency were observed [24].

Variation in prices of vegetables and pulses is an issue and can be dealt with by early detection and remedy in crop diseases.

In this study social media is used as knowledge-intensive process to address issues of text and images of plants to meet farmer's queries [25].

3. Discussion

This study is conducted to compare the applications of various deep learning tools using IoT and how they can be applied in the field of agriculture. It is a qualitative study. Qualitative Research is mainly done for exploration and deduce some results. It is used to gain an understanding of underlying reasons, opinions, and motivations. It provides insights into the problem or helps to develop ideas or hypotheses for potential quantitative research. This study analyzes the past research papers as well as proposes some deep learning tools that can be applied to achieve better results in various aspects of agriculture.

Deep learning enables multiple processing layers to learn representations of data with many layers of abstraction. Hence these techniques have immensely improved results in speech recognition, visual object recognition, object detection and many other domains such as drug discovery and genomics. Deep learning discovers intricate structure in large data sets by using the backpropagation algorithm to indicate how a machine should change its internal parameters that are used to compute the representation in each layer from the representation in the previous layer. Deep Convolutional Networks (DCN) have breakthroughs in processing images, video, speech, and audio, whereas recurrent nets have shown a light on sequential data such as text and speech.

Precision agriculture is also known as smart farming. It is the latest development in the field of farming. It was firstly applied in manufacturing industry in 1970's till 1980's. It covers the monitoring and intervention techniques in order to get efficiencies as well as better production. Due to the Spatio-temporal variation in soil and climate it requires precision agriculture. Intelligent machines are being built to achieve better results. Sensors are being placed on robots to collect information related to soil, seeds, crops, costs, farm equipment and use of water and fertilizer. Reduction in costs of IoT technologies and improvement in analytical tools is helping farmers analyze data related to weather, temperature, moisture, etc. It enables farmers to decide how to reduce wastages and increase yield [26].

Fig. 2. below shows the existing framework of IoT in agriculture. It shows various inputs, such as, soil, water, and energy, which play a vital role in crop production. Also timely use of quality seeds and fertilizers results in higher production. Pesticides, fungicides, and equipment used also enable farmers get better results as a precaution to avoid various diseases spread in crops.

All these inputs are applied to the crops, livestock as well as fisheries and so crops are grown and harvested. Farmers also need storage facilities and timely transport them for usage as food or manufacturing other products from these crops and finally they are sent to retail for consumers.

One of the Deep Learning Techniques is Auto-encoder Neural Network. It is an unsupervised algorithm [28]. It is composed of 3 parts, an input layer, one or more hidden layers, and an output layer. The input layer and output layer has same number of nodes while hidden layer has lesser nodes than input layer. The training process comprises 3 stages pre-training, unrolling and fine-tuning. In pre-training each neighboring set of two layers is modeled as a Restricted Boltzmann Machine (RBM). Now the deep learning network is unrolled to obtain the reconstructed input with forwarding propagation. Back-propagation technique is used for results to be fine-tuned. This technique is widely used in activity recognition and health sensing applications.

Another technique is the Convolutional Neural Network. It is done by depicting how living things develop their visual

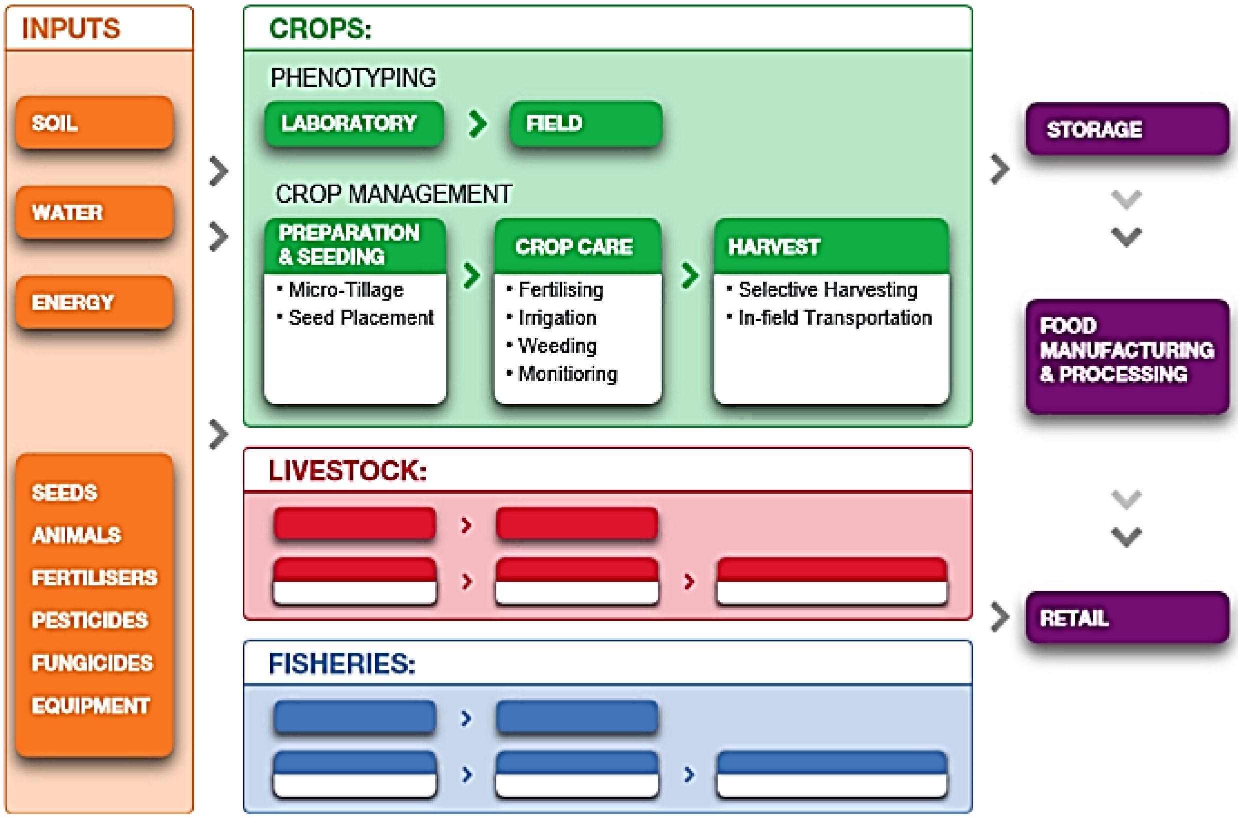

Fig. 2. Opportunities for Robotics and Autonomous systems in agriculture Ref. [27]

perception and is used successfully in computer vision [28]. Its first architecture was LeNet-5. The convolution and sub-sampling operations are applied to input data in respective layers. Two groups of computations the output layer is processed via a neural network resulting in improved classification results. Microsoft improved the results via residual learning network ResNet [30].

A third technique is Long Short-Term Memory (LSTM). It was developed to handle data with long-term dependencies. It uses 3 gates to control the data flow. The input gate decides new data value to be entered, forget gate controls if retain or forget this value and output gate decides if this value can be utilized in output calculation for the unit [30] . The gates are an effective way to optimize training of LSTM. It is used in machine translation, speech recognition, and time series prediction.

4. Results and Findings

Fig. 3 below shows various IoT sensors and their uses in the measurements of field inputs. Detailed sensor names are shown below. A modified framework has been proposed, which shows the relationship between various field inputs and their connectivity with IoT sensors to gather data for further processing, as shown in Fig. 4.

Our proposed framework covers various inputs including soil condition, pH value of soil, water condition, energy, seeds, animals, fertilizers, pesticides, fungicides, and equipment used. The inputs are connected via WiFi or RFID or Bluetooth. These devices are powered by solar panels with batteries to enable them work throughout day and night. Various IoT sensors are used for monitoring the field's inputs. The soil moisture sensor is used to monitor the contents of moisture in soil and data can be used for automated irrigation planning, climate research.

Evaporation and transpiration are key players in soil moisture maintenance. pH Value sensors are used to monitor the land suitable for every crop being planned for cultivation. Location Sensors are used monitor the agriculture equipment as well as animals. Land characteristics are also monitored.

Optical Sensors use optical technology to measure soil properties. They are also used for better use of fertilizers, pesticides, and fungicides. They can be placed on vehicles, drones or even satellites for effective use.

Animals can be equipped with collar tags to give their health information. Also, their temperature and nutritional insights can be gathered for individual animals as well as herd. Electrochemical sensors are also used to gather pH and soil levels for the field.

Mechanical sensors can also be deployed to measure soil compactness and its resistance. Dielectric sensors also

IoT Sensors

Field Inputs	S.M.S	L.S	O.S	C.T	E.S	A.F.S	N.S	I.S	A.S
Soil	✓	✗	✓	✗	✗	✓	✓	✗	✓
PH Value	✗	✗	✗	✗	✓	✗	✗	✗	✗
Water	✓	✗	✗	✗	✗	✗	✗	✗	✗
Energy	✗	✗	✗	✗	✗	✗	✗	✗	✗
Seeds	✗	✗	✓	✗	✗	✗	✗	✓	✗
Animals	✗	✓	✗	✓	✗	✗	✗	✓	✓
Fertilizers	✗	✗	✓	✗	✓	✗	✓	✗	✗
Pesticides	✗	✗	✓	✗	✓	✗	✗	✓	✓
Fungicides	✗	✗	✓	✗	✓	✗	✗	✓	✓
Equipment	✗	✓	✓	✗	✗	✗	✗	✗	✗

Legend: ✓ = sensor is used
✗ = sensor is not used

*S.M.S = Soil Moisture Sensor, L.S = Location Sensor, O.S = Optical Sensor

* C.T = Collar Tags, E.S = Electrochemical Sensors, A.F.S = Airflow Sensor

* N.S = N-Sensor, I.S = Image Sensor, A.S = Acoustic Sensor

Fig. 3. Field Inputs vs IoT Sensors

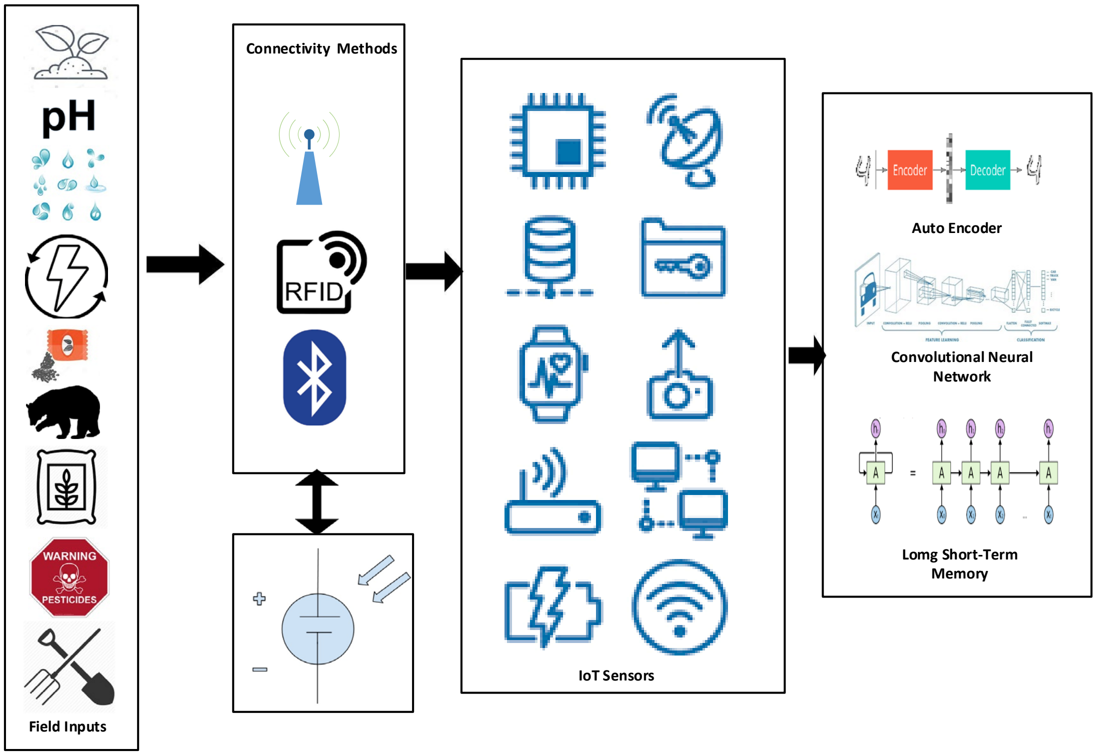

Fig. 4. Proposed Framework

measure soil moisture. Airflow sensors are used to measure soil permeability.

It is also used to detect soil compaction, structure, soil-type and moisture level. N-Sensor is used to monitor the nitrogen level in crops. It guides us to maintain the fertilizer requirements of a specific crop.

Image sensors are used to monitor seeds, animals, pests as well as diseases in crops. Acoustic sensors are used to detect insects or pests attack at the initial stage for the protection of crops. They are also used to monitor animals as well as soil conditions. All types of data from sensors are automatically transmitted via Wi-Fi, RFID or Bluetooth to the data server for further processing.

Deep learning algorithms are applied to real-time data to enable better decision making for crops. The field can be divided into various zones and a yield map prediction may enable farmers to concentrate on those areas with low yield prediction and finding the factors responsible can empower farmers to mitigate the reasons for low yield prediction in real-time to improve the yield.

5. Recommendations & Future Work

We have developed a framework for the crop data gathering using various IoT sensors to make decision making easier and application of automated systems. The application of these automated systems in the field of agriculture will act to revolutionize the whole scenario and enable farmers to meet the increasing demand for food for the world. Early detection of a disease can help mitigate the disease and protect crops.

Automated spray with the use of crop images and drones will help reduce the use of pesticides with better crop protection. Irrigation monitoring using sensors will enable farmers to maintain the proper supply of water for soil moisture without any water wastage. Various other types of sensors can be used to monitor soil conditions such as pH value, airflow etc. and their live connectivity with our automated system will enable us timely decision making to reduce any type of losses.

Deep learning methods are computation extensive and require high memories as well. Currently the data processing is taking time and needs to be reduced. In order to reduce the delays in future some technology may be adapted to process the data at the user's end by deploying intelligent sensors and smart devices. Security and privacy protection for the data is another issue that needs to be addressed.

The future of agriculture is smart agriculture using intelligent IoT with the deployment of deep learning to enable automated decision making and better crop production. Future directions include application of smart and intelligent sensors and devices at nodes for better decision making and reduction in processing at server end.

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