

Machine Learning-based Data Fusion Technique for Irrigation Management in Multi-Crop Framework

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Abstract—The development of smart agriculture depends on the irrigation system which is the main factor in crop growth. Therefore vast research is taking place in the smart irrigation system of smart agriculture that involves IoT, machine learning methods, hybrid techniques, etc. To obtain the maximum yield from the soil, a multi-cropping system is introduced that grows various crops in the same agriculture field that are selected based on the soil fertility and crop genome. Many sensors are deployed to enhance the irrigation system which increases the amount of data that needs to be communicated. Data fusion is a technique that reduces the dimension of the data and combines all modes of data, is an efficient method to resolve this issue. Therefore, this paper proposes the data fusion technique based XAI approach and ensemble transfer learning technique for decision-making process to manage the irrigation in the smart irrigation system. The LIME-based XAI model is used to increase the fusion level. Ensemble transfer learning increases the prediction accuracy of the system with the previous iteration dataset with the ensemble groups of training and testing.

Keywords— Smart irrigation, XAI, ensemble learning, transfer learning, data fusion.

I. INTRODUCTION

Smart Irrigation system is the main component of the smart agriculture which helps to decide the water requirement of the crop using various technologies.

Growing population increases the agriculture demands that directly increases the technological development of the smart irrigation system. IoT is used widely in various sectors, here the smart irrigation system also benefitted with the help of it. on the other hand machine learning and deep learning techniques involved in various stages of the smart irrigation system to enhance the operation in order to obtain the economical agriculture module.

In the paper [1], the survey on IoT (Internet of Things) based crop monitoring system for different data fusion platforms using different sensor types for various parameters are considered.

The parameters like nitrogen, chlorophyll, leaf area index, and above ground biomass parameters are calculated using the data collected from the optical, thermal infrared, multispectral and hyperspectral and LiDAR (Light Detection and Ranging) sensors which is fused using data fusion platforms like ground based, aerial based, and space borne platforms.

Big data analytics plays a vital role in the smart agriculture where the irrigation managements needs more attention is addressed in the paper [2] where the authors discussed wide aspects on the crop evapotranspiration calculation and estimation methods based on crop type, climate and growth stages, irrigation scheduling methods like border, drip and sprinkler irrigation methods and their needs, decision support system based on statistics, machine learning, deep learning and big data analytics are discussed in detail. The authors in the paper [3] reviewed 386 articles based on remote sensing techniques for crop mapping in order to face the crop mapping issues in the food production for the growing population. The LiDAR based remote sensing images are used for crop mapping with the help of big data analytics, deep learning and supervised machine learning techniques and concluded that LiDAR and hierarchical method of crop mapping is best one in food production. The smart farming techniques using deep learning techniques for sustainable agricultural development that leads to enhanced economical growth is the objective of the paper [4] where the authors explained different supervised learning networks CNN (Convolutional Neural Network), Alex Net, Resnet, and Recurrent Neural Networks for analysis on crop yield prediction, smart farming, pest detection, weed segregation, disease findings, and plant stress detection data are obtained is explained. Mapping crop rotation is the important criteria in the efficient usage of soil based on the nutrient contents the crop are cultivated this needs an analysis which is carried out using the CNN based LSTM time series method in the paper [5] that obtained good accuracy and provided the ecosystem management data to greater extent.

In the paper [6], the irrigation strategies that fix the agriculture yield based on the parameters like amount of crop yield, total irrigation and financial outcomes using the Optimizing model considering the analysis of sensitivity, optimisation and uncertainties based on climate forcings is discussed. The Secure Multi-crop Smart Irrigation System (SMSIC) is introduced by the authors in the paper [7] where the access control and blockchain used for security and integrity of data collected by the soil moisture sensor and climate prediction sensors in order to obtain the evaporation constant to obtain the amount of precipitation after irrigation is carried out. The discovery of crop information and decision is made using the data collected from the multi agents system (MAS) that are collected using the sensors from the Wireless Sensor Network (WSN) from the field where using the proposed method authors in the paper [8] reduced the water consumption by 17.16% effectively in corn yield. The spatiotemporal data fusion methodology is used in the paper [9] where the data fusion is done in three phases like data in feature out, data in feature out, and feature in decision output using genetic algorithms and Particle Swarm Optimization algorithms. LoRa (Local Range) WAN (Wide Area Network) model framework is designed in the paper [10] to maintain the connectivity between the sensor (valve and sensor nodes), cloud and users where the data fusion is carried out using the LSTM (Long Short-Term Memory) for predicting the weather forecast based on it irrigation is carried out. Hydra modelling is used in the smart agriculture which is composed of sensor data fusion, event and decision data fusion and multi-application-based data fusion using the Support Vector Machine (SVM) the evapotranspiration model is estimated for smart irrigation systems is proposed in the paper [11]. The Water Need Estimation (WNE) helps in the amount of irrigation required, electricity usage and to address the water scarcity issues is surveyed in the paper [12] using data driven approaches. Fog Computation is introduced in the paper [13] to maintain the seamless connectivity between the sensor nodes and the cloud server and also authors used kNN (k-Nearest Neighbour) to estimate the missing dataset for predicting the water requirement. Smart agriculture data management based on the data fusion where the quality, damage and smart planning are analysed in the paper [14] based on the aerial, satellite, proximal and ancillary data basis. To overcome the sustainable exploitation the authors in the paper [15] uses the decision support system using the multi sensor data collection to control the amount of fertilizers and pesticides usage in the agriculture. The incorporation of cloud, data mining and android based mobile application is proposed in the paper [16] where the collected data from the sensors are stored in the cloud and communicated to smart phones from where the drip devices operation is decided. The area using 2G and 3G wireless mobile networks are beneficial using the IoT based smart irrigation system proposed by the author in the paper [17] where the work shown better result in terms of network stability. The efficiency of the Mobile Robots for high intelligent system based on fuzzy system and equalisation method is employed in the paper [18]. Deep CNN based computer vision technique for soil texture identification to meet out the water shortage issues is examined in the paper using other 5 deep learning techniques where the CNN detects the soil texture efficiently compared to the other neural networks explained in the paper [19]. The paper [21] surveyed various topics of irrigation analysis, methods, techniques using machine learning and artificial neural networks and control policies in the smart irrigation system. The IoT-based smart irrigation system reviews on the basis of soil and weather monitoring, water management, communication, and cloud technologies in the IoT, pros and cons, barriers, and big data optimization is explored in the paper [22]. The monitoring and controlling the irrigation system with the help of sensors and actuators is discussed in the paper [23] where the authors used IoT platform for smart irrigation

monitoring and control. A DSR approach is framed in the management of sustainable irrigation system study is taken by the authors in the paper [24] where their objective is to address the water scarcity issue and they implemented the project. The problem of stakeholders in data conversion is explained in the paper [25] where the authors indulged IoT, Big data, and smart irrigation system to reduce the water need by accurate evaluation of the water need of the crop based on the sensed data that manipulates the weather condition, rainfall prediction, humidity, and moisture content in the soil. Explainable Artificial Intelligence (XAI) is the trustworthy AI based machine learning method that is incorporated in data fusion technique to make the output more accurate in the medical field [31].

From the survey, the need for improvement in data fusion and decision making process in multi-crop framework has to be done. So this paper proposes the multi-crop framework using XAI based data fusion technique and ensemble transfer learning based decision making process for irrigation management in smart irrigation system. The paper is organized as follows, i) Introduction, ii) IoT based smart Irrigation system, iii) Machine Learning methods, iv) Proposed work, v) Results and discussions, and vi) conclusion.

II. IOT-BASED SMART IRRIGATION

The Internet of Things availing the wireless communication standards, collects the sensed data from an environment, acquires the data, store the data in the cloud server. The clients or actuators based on their need obtain the data from the cloud server and make the necessary decisions. The main models of IoT systems are sensors, cloud servers and user interfaces. The development in the wireless technologies and wide range sensors are manufactured there is a extensive growth taking place in the IoT systems [26]. IoT finds its application in medicine, agriculture, military, unmanned areas, etc. the flexible modeling of IoT system is its main advantage were based on the application the IoT system can be framed accordingly. There is no restrictions or limitation to usage of IoT system model where the researchers utilize different sensors, wireless technologies, machine learning methods and user interfaces that enhances its adaptive nature.

Smart agriculture is one of the IoT applications where various parameters from the agriculture field are sensed and the data are collected that is sent to the cloud server, based on the information obtained the farmers or the actuators take the necessary actions [27]. The IoT divides agriculture into sectors and function, that improvise the smart agriculture day by day. The various IoT applications in the smart agriculture are discussed below.

- Crop management – crop growth, single or multi crop cultivation, requirements of the crop, etc
- Smart irrigation- water requirement, amount of water required for single or multiple crops, forecast, etc..
- Soil quality monitoring- soil moisture sensor, humidity, nutrients, weeds control, etc..
- Weather monitoring - weather forecast for rainfall, sunlight, humidity etc.
- Smart greenhouse – heat, humidity and light control for the plant growth well-being.
- Pest management – pest-affected plants, amount of pesticide required, type of pesticides, etc..
- Disease management and control- sudden damages due to particular diseases in plants, necessary pesticide selection, disease control management, etc.
- Water management- amount f water required based on the crop either single or multi crops, focusing the water scarcity and shortages issues, etc
- Crop mapping- based on the soil quality crop mapping takes place to utilize the agriculture field to the greater extent.

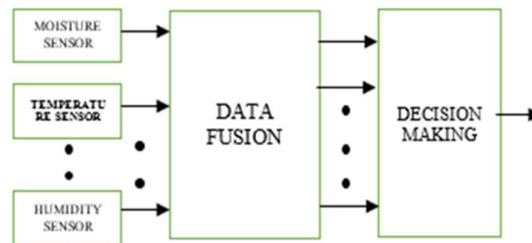


Fig. 2. Smart Irrigation Framework

Smart Irrigation plays the major role in the smart agriculture which utilizes the IoT system at larger scale. The smart irrigation system is the main requirement in the agriculture where the plant growth is fully dependent. The growing population requires more food production on the other hand water scarcity issue also increasing. In order to address those issue, smart irrigation act as the best solution that overcomes many issues in agriculture.

Fig. 2. Depicts the smart irrigation system, where the data collected from the farm using various sensors like moisture sensor, temperature sensor, humidity sensor, weather forecast sensor, etc are combined using the data fusion techniques and the necessary decision is made using the machine learning algorithms. The conventional smart irrigation system consists of sensors for data collection, a cloud server and a user interface using the mobile application or the actuators that function according to the information collected by the sensor like switching ON/ OFF the water pump based on the water requirement analysis. However for large-scale cultivation, the conventional method requires more innovations and designs. Therefore many ML algorithms are incorporated for decision making and data fusion processes. The main objective of smart irrigation is to manage the water crisis in various parts on countries and also to maintain the plant growth at good rate with available amount of water. The former method uses water without the knowledge of the requirement of the plant growth and moisture already present in the soil. But the smart irrigation system, used different methods of irrigation technique based on the field and crop requirement that helps in the reduction of water usage. The plant growth will be destroyed if more water content present in the soil. Some times humidity and the weather conditions spoil the plant growth, so the sensors based on these parameters are involved in the smart irrigation systems to maintain the plant growth.

Fig. .3 shows the various ways the data in the smart irrigation system undergoes to obtain fruitful actions. Data collected and stored in the conventional smart irrigation system is not enough nowadays to meet the enormous amount of food production that too takes place throughout the year. Therefore, various data processing techniques are involved to manage the amount of data collected from the field, process it, and decide based on the output. It is most important to reduce the amount of data collected to reduce the storage in the cloud server. Because the sensing operation is going to takes place round the clock, sometimes there will be a collection of redundant data that are not actually required for decision processes. Therefore, many techniques are employed in the data processing and analysis in the smart irrigation to reduce the data size. On the other aspects, the various sensor collects various data of various formats, therefore combining all this data in the packets is a complicated task. It is necessary to map all the data in a single format for efficient storage and usage in future purposes. In the decision-making process, the actual data that has the meaningful information are given more importance than the redundant and unwanted data. So it is necessary to involve various data processing techniques that to overcome above issues discussed in the data processing and data analysis in the smart irrigation system.

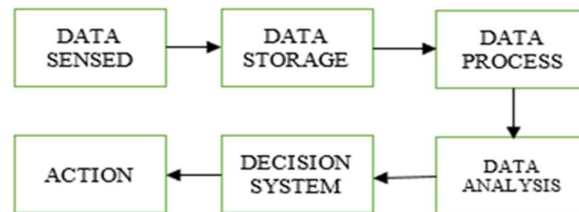


Fig. 3. Smart Irrigation Data Requirements

A. Data fusion in smart irrigation

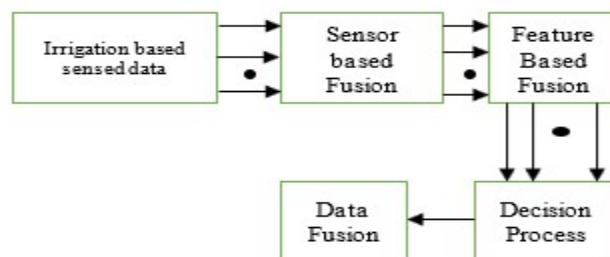


Fig.4. Data Fusion Processes

Data fusion is a technique that employs multiple sensor output and frame it into single data output. It helps to reduce the dimension of the huge amount of data collected from the environment. This reduces the data redundancy at large scale where many sensors are employed to collect same data that accumulates more amount of similar data. This reduction in dimension and data size, helps to reduce the resource usage in the cloud and the user end. The main objective of data fusion is to convert the multi-modal data sets into a single data set of unique

formats that helps to obtain the accurate result in the decision-making processes. Fig.4. depicts the data fusion processes from a smart irrigation system [20].

The data collected from the sensor network contains multimodal data sets like moisture content, temperature measurement, nutrient quantity, humidity in the atmosphere, etc. These data are then undergoing fusion in the sensor level and then features are extracted from it. With the help of features extracted, fusion takes place and at final phase, the decision-making processes are used to obtain the accurate results. The feature extraction and decision-making processes are highly depending on the machine learning and deep learning techniques which with the help of previous dataset or training datasets, obtain the precision accuracy at larger scale.

B. Multi crop framework

To maximize the yield of the soil in the agriculture the multi cropping system came into play. Multi cropping is usage of different crops to grow in the same field but with different characteristics [28]. This is the actual ideology of suppressing the weed plant growth instead a crop plant can be grown that utilizes the soil nutrients instead of weeds. There are three necessary functions need to be done for growing multi cropping system that are discussed below.

- Ecosystem services and function – this is to identify the location where the multi-cropping system can be carried out based on the soil fertility and nutrients.
- Species selection – based on the soil quality, the genome crops are chosen for sowing purposes.
- Management strategies – here different crop requires different water needs, nutrients, moisture etc, these things need to be addressed.
- The proper framework based on above functions is required for effective outcome of multi-cropping system which has more practical difficulties.

III. MACHINE LEARNING METHODS

IoT system emerging with various machine learning techniques that helps in the production of accurate data results from the huge amount of sensed data. The machine learning process is of many types like supervised, unsupervised, and trustworthy means. Depending on the application of IoT machine learning methods are employed like feature extraction, classification, decision making, fusion, etc. Of many techniques available, ensemble transfer learning [31] and Explainable AI (XAI) gains more attention in the research.

A. Ensemble Transfer learning

Ensemble transfer learning combines the advantages of both the ensemble learning and transfer learning techniques. The transfer learning is a well-known technique for predicting the new output with the help of knowledge from the old domain that has been processed already. This helps greatly in the future predictions of various domain using the previous domain model.

It doesn't need training models for every instinct as it uses older output method has training model to the new inputs. On the other hand, ensemble learning is method of grouping multiple inputs in various sets and train them individually. It shows high precision accuracy compared to other machine learning techniques because it trains and test the multiple data with their corresponding data sets individually.

The ensemble learning categorized by bagging, stacking and sequential methods. The transfer learning also categorized into positive, negative near and far transfers. Combining these two techniques helps in precision accuracy with the future prediction that helps greatly in the real time data basis functions. Smart irrigation system is the real time data basis which requires more accuracy and future prediction algorithm, where the usage of ensemble transfer learning efficacies the system even more.

B. Explainable AI

Explainable AI is invented to unbox the unknown hidden neuron function taking place without human intervention. It is most required to explain the output occurrences for each and every input where the current machine learning and deep learning model fails.

The explained output gives the good insights on the process taking place that leads to framing a successful model that will not fail at any cost. Thus, it becomes the trustworthy system AI model. Based on the questionnaire arised from the researchers, XAI is divided into four types like based on the number of models, either entire or sample of the models, based on the occurrence and based on the complete or part of the model. Current researches are focusing on XAI models incorporation in almost all the machine learning techniques to build a trustworthy one. Data fusion is sector that needs more explanatory in terms of fusion level basis, therefore usage of XAI in data fusion benefits a lot to the framework.

IV. PROPOSED FRAMEWORK

As discussed earlier, Multi-crop framework comprised of different crops cultivation in the targeted location based on the soil fertility and genome type of the crops. It is done to utilize the area and soil of the cultivation efficiently avoiding the growth of weeds that consume the soil nutrients leading to waste. Multiple sensors are used in the multi-crop cultivation area to manage the irrigation system efficiently. The irrigation system for multi-crop system should be more efficient compared to the single-crop system because different crop requires different water intake. It is the objective to grow multi-crops with good quality that needs a proper smart irrigation system. As many sensors are involved in the collection of required data from the soil and atmosphere, the huge amount of data needs to be transmitted to the cloud server and to the user end. This results in inefficient resource management and more redundant data makes the resource waste.

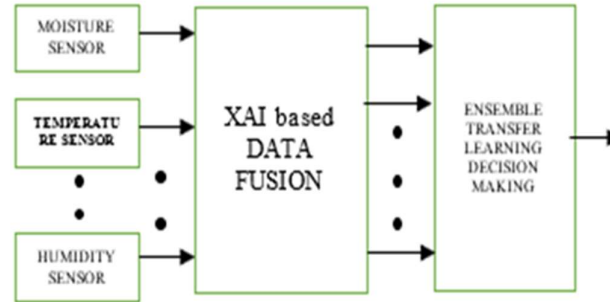


Fig. 5. Proposed model

Data fusion is the technique that combines all the multi-modal data sets and reduces the data dimensionality at a greater rate. Hence this paper proposed the technique of using data fusion technique in smart irrigation system. As the data fusion techniques involve feature extraction and decision-making processes, those processes all remain unexplained which leads to the uncorrectable errors that occur in the system. To avoid this, this paper uses XAI based data fusion technique and uses the ensemble transfer learning technique for future prediction with maximum accuracy.

The Local Interpretable Model-Agnostic Explanations (LIME) based XAI is incorporated in the data fusion technique of the multi-crop framework approach proposed model. The algorithm explains the way the LIME model applied to data fusion technique.

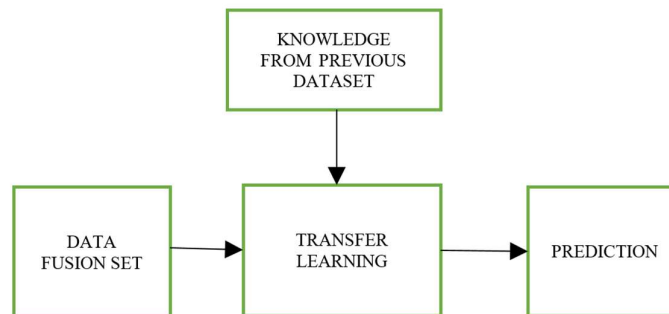


Fig. 6. Transfer Learning model

Fig.6. shows the prediction of data from the data fusion datasets using the transfer learning model. The transfer learning model relies on the previous trained model for predicting the future.

The sensed data undergoes data fusion at three stages: sensor data fusion level, feature level, and decision level. In the feature level, the XAI model is used to answer the unexplained features using the RBF kernel and linear regression model. These spots are formulated, explains and then sent to decision-making processes where the ensemble transfer learning model is applied to predict the output. The transfer learning using a data fusion dataset predicts the future and sends it to the ensemble learning to improve the accuracy. Since a multi-cropping system requires high precision accuracy to know which crop requires what kind of need, the proposed approach helps to maintain the efficient irrigation system using accurate prediction and resource utilization.

V. RESULTS AND DISCUSSION

The proposed work of using the XAI model for data fusion technique and ensemble transfer learning for decision-making for irrigation management in multi-cropping framework is explained and simulated using five type of sensors for measuring moisture, humidity, temperature, rainfall, and nutrients in the soil. For training machine learning, Intelligent Irrigation System dataset is obtained from the Kaggle website. It contains sensor data on moisture, temperature, humidity, rain, and nutrient present in the soil. It also stores the pump on and off condition that helps in training the transfer learning algorithm.

The plot of the number of iterations versus the fusion percentage for the proposed method of using the XAI model in the data fusion technique for the smart irrigation system. Here the five different sensor data are combined in the feature level using the XAI model. A standard value is taken as a reference in the plot, where the proposed approach is almost equal to the standard value this shows the efficiency of the proposed method. The XAI model with the help of linear regression and RKF kernel finds the unexplainable features and solves the issue that greatly helps the data fusion technique a trustworthy model. It is seen that the proposed model shown 20% higher efficiency compared to the conventional method of data fusion technique. This means 20% of the conventional method accuracy is reduced due to the unexplanatory issue in the hidden neurons that is efficiently solved by the LIME method, the training accuracy plot for the ensemble transfer learning algorithm used in the decision process of the smart irrigation system. This graph proves that the accuracy increases with the iteration which means transfer learning with the previous knowledge of datasets efficiently increases its prediction accuracy level. The proposed algorithm is compared with the conventional ensemble learning algorithm where the proposed algorithm shown 35% more accuracy.

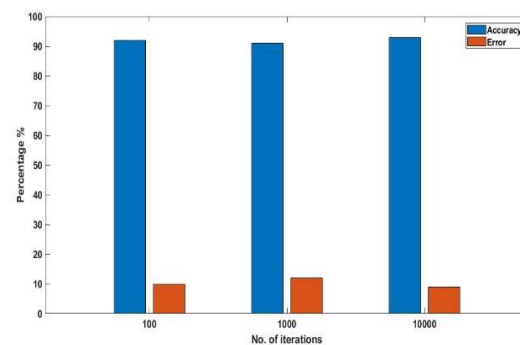


Fig. 11. Multi-Crop Framework Complete Accuracy and Error Percentage Calculation

Fig. 11. Shows the bar graph of accuracy and error obtained for the proposed of using multi cropping framework using XAI model data fusion and Ensemble transfer learning based decision making algorithm in the smart irrigation system. the plot is obtained at 3 different iterations using five different sensor data as inputs. It is seen that the accuracy remains approximately 90% for all the three iterations this shows the stability of the proposed work. The error remains less than or equal 10%.

VI. CONCLUSION

The proposed approach using the XAI model for data fusion and ensemble transfer learning for the decision-making process in smart irrigation systems is presented. The simulation carried out for the proposed work using five data sensor output that is combined using the XAI model data fusion technique at the feature level and applied ensemble transfer learning to predict the action from the irrigation management for the smart irrigation system. the proposed approach shown good accuracy compared with the conventional approach.

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