Low-cost smart farming in a shared approach using internet of things and machine learning

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ABSTRACT

In this paper, a concept of shared approach of smart farming system is discussed. The technique utilizes the ability of machine learning (ML) and internet of things (IoT) enabled sensors. Additionally, to implement this approach a layered architecture is also proposed. The layered architecture is providing the steps to achieve this model practically by using a cooperative manner. This technique is providing the smart farming services as plug and play basis. Therefore, the complexities of management and implementation is also considered at the billing and maintenance level. Additionally, a conceptual solution for the particular complexity is also suggested. The model can also motivate the new entrepreneurs to adopt the model and serve for the smart farming as service.

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1. INTRODUCTION

Climate change, global warming, the water crisis, and flooding are all global issues [1]. These issues affect not only humans, but all of the world's creatures. Among various emerging issues, food and water security is a major concern [2]. However, a number of government and non-governmental organizations are launching initiatives to improve sustainability and food security [3]. Agricultural reform is an important part of these reforms because it consumes a lot of fresh water and pollutes the water after it is used for farming [4]. As a result, improvements are needed in the traditional farming sector as well. In this context, researchers and scientists are developing advanced techniques to promote sustainable farming [5]. These technologies have become popular among us under the names smart farming and precision farming. Both technologies use new generation cutting-edge technologies to assist farmers with various activities and complexities in farming practices [6].

Both techniques (smart farming and precision farming) use internet of things (IoT), sensors, networks, cloud servers, cameras, drones, and other advanced technologies to help with various complexities such as irrigation, fertilizer treatment, pesticide treatment, disease identification, crop and intruder monitoring, harvesting, and other activities [7]. As a result, both the quantity and quality of production have improved. However, implementation and maintenance are prohibitively expensive for small farmers [8]. As a result, small farmers in India find it difficult to accept. However, in India, more than half of the population works in agriculture, either directly or indirectly. However, only 5% of farmers are able to use expensive technologies [9]. On the other hand, the remaining farmers only do this business for a living. Furthermore, they are making very little profit. The main reasons for this are: having poor financial conditions, less awareness and education level, use of only owned resources and conventional techniques, and fighting for survival.

As a result, the acceptance of advanced technology in Indian farming scenarios is extremely complex and difficult to achieve. On the other hand, the growing population and global demand for food security are motivating us to take the first step toward developing a community-driven shared smart farming module to assist low-income farmers. The proposed concept outlines how to create a smart farming system using limited and collaborative resources and efforts. Thus, the main aim of the work is to develop a low-cost and shared smart farming infrastructure by using machine learning (ML) and IoT to offer benefits to low-income Indian farmers. To introduce the presented work, this paper is organized as follows: i) this section highlights the need for a shared approach to smart farming modules; ii) the following section highlights recent progress using sensors, IoT, and ML. In addition, the trend of using these technologies in the farming sector was discussed, iii) the third section is divided into three sub-sections. The first section provides an overview of the infrastructure and its components. The second section discusses the experimental data and the required preprocessing technique, while the third section demonstrates how to operate an automated irrigation and fertilizer treatment system in shared conditions, iv) the fourth section outlines a cooperative implementation strategy, and v) finally, the proposed work concludes with suggestions for future improvements.

2. LITERATURE REVIEW

2.1. Noteworthy contribution

The main aim of this review is to explore the domain of applications, where the ML techniques are playing in critical role for decision making. Initially, two noteworthy contributions have been explored, first is contributed by Doshi *et al.* [10]. They will assist farmers by providing land conditions, so that they can take the necessary steps. Second article is contributed by Rekha *et al.* [11]. They were discussed a framework for improving agricultural practices and land use. The goal is to sense and advise farmers on how to grow and treat their crops, regarding crop irrigation and fertilizers. They were used wireless sensor networks (WSN) for data collection and messaging. For practically implement the sensor networks, we need to understand the IoT. Thus, first an article contributed by V. Saiz-Rubio and Rovira-Más [12] has been investigated. This system is including cloud, big data and analytics. Kalyani *et al.* [13] generate messages to notify farmers. That will assist farmers by getting data from the land to take necessary steps to do. Akbar *et al.* [14] address the challenges of dairy farmers. They provide a system to improve yields, composts, and disease information. Shipa *et al.* [15] investigated a portion of IoT in agriculture. It provides the ability to improve yields, composts, and disease information. Kulkarni *et al*. [16] proposes a solution for smart farming using IoT. Aggarwal and Singh [17] discuss IoT applications in agriculture. It allows prediction that contribute to the profitability of agriculture. They use WSN for soil condition monitoring. For exploring more in WSN applications in agriculture we have studied an article contributed by Varsha *et al.* [18]. The soil has been evaluated, and crop and fertilizer recommendations have been made. They had been achieved a balance between sensor energy efficiency and phosphorus measuring accuracy.

Wang *et al.* [19] introduce SmartHerd, a fog-assisted IoT platform for animal behavior analysis and health monitoring. It is designed to facilitate distributed computing and connectivity. The implementation uses the data from wearables to aid decision-making and provide actionable insights. Ilyas and Ahmad [20] use a case study to discuss the use of cloud and IoT for solution design. An irrigation system was developed using the message queuing telemetry transport (MQTT) protocol, which is both energy efficient and faster. Tripathi and Maktedar [21] use IoT and ML to classify soils based on their characteristics and recommend the best crop.

An introduction to SDF has been presented. A focus on assisting farmers using IoT. Rehman *et al.* [22] used IoT to create a smart greenhouse, which replaces the traditional interface, lowers the barrier to technology, inspires a variety of applications, and increases production. M *et al.* [23] propose a solution for tracking and geofencing. Create a safe zone using IoT and GPRS. Shruthi *et al.* [24] use IoT and machine learning to classify soils based on their characteristics and recommend the best crop. Cattle can be monitored and controlled using data collected. Next, to understand the components of IoT enabled farming an article has been studied, contributed by Bolfe *et al.* [25]. Zolghadr-Asli *et al.* [26] propose an irrigation solution to reduce water waste. They discussed automation components such as IoT, wireless communications, ML, and artificial intelligent (AI). Crop diseases, storage management, pesticide, weed management, irrigation, and water management are all issues to consider. Automation has proven to increase soil productivity and fertility. Additionally, discusses precision agriculture and components used were discussed.

Here, we observed, the sensor based collected data needs advance data processing techniques to generate actionable insights. In this context, first we studied a review paper contributed by Dahane *et al.* [27]. This paper is focused on fruits and vegetables, agriculture fields, models, data pre-processing, analysis, and accuracy. They investigated the type of disease and compared ML approaches, concluding that SVM provides higher accuracy. Similarly, Almalki *et al.* [28] describe the application of ML in agriculture.

3. PROPOED WORK

3.1. System overview

Farming is more than just a series of processes or instructions that are carried out in a specific order. That is a work of expertise and experience that requires careful observation and decision-making to optimize crop production. Among the many sub-processes involved in farming, proper plant water and fertilizer treatment is critical for effective crop growth and production. However, the implementation of smart technology in the Indian farming scenario can be costly for individuals. As a result, we propose developing an accurate and efficient ML model to predict treatment plans based on sensor readings. Figure 1 presents an overview of the proposed model. A group of farmers can work together to establish a support infrastructure. They can deploy IoT-enabled sensor nodes on their own farmland to monitor soil conditions. The collected sensor readings are being sent to the server. The server uses the current readings to determine the appropriate water and fertilizer treatment. The trained ML model predicts based on historical sensor readings labeled with the appropriate treatment type. The trained ML algorithm evaluates current sensor readings and predicts the treatment plan.

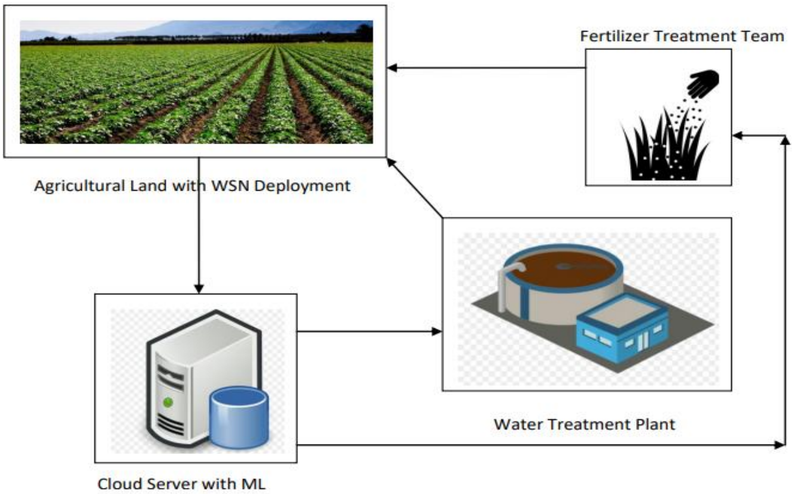

Figure 1. Proposed system architecture

The proposed model includes the following components:

a. Sensors network in farms: the IoT-enabled sensors are deployed on collective agricultural farms. The sensors were placed on farmland within a communication range to collect and transmit data to the cloud server. These sensor nodes are designed to gather data from the soil. For this purpose, we can use Soil Hygrometer for Arduino, which is a low-cost sensor and able to detect the moisture in soil. This module can be paired with ESP32-S3 for communication. Both the modules are costs approximately 500 INR, but bulk amount of purchase may reduce the cost more.
b. Cloud server with ML model: cloud servers are high-performance server infrastructures capable of collecting and processing large amounts of data. The ML models are trained to analyze historical sensor data and recommend the best treatment plan. For real time data management, the system can be using Google Firebase. Additionally, to execute the ML algorithms, we can use the Google computing engine, which works on plug and play mode. The google allow the transparent billing and charge only when the server in use.
c. Water treatment plant: the water treatment plant is a common water supply unit that may be built to serve several farms. The cloud servers send instructions to the water treatment plant, which can then enable or disable water supply.
d. Fertilizer treatment plant: similarly, the system includes a fertilizer and pesticide treatment unit, which also receives instructions from the server. These treatment systems are designed to receive instructions from the server and respond appropriately. For both the treatment plants, we can use SAIER SEN-SZ21WA Water Solenoid Valve, which is low-cost and easily available in Indian market and online e-commerce. This type of valves is low-cost which may available in a cost of 530 INR.
e. ML models: the cloud server houses the model's hidden component. The cloud server executes the ML models to process sensor readings and generate instructions for the other components.

f. Security and privacy: in a multi-party data sharing and decision-making systems the privacy and security are a complex issue. In this context, the system can use the privacy preserving data mining (PPDM) models for controlling the security and privacy of all the collaborating parties.

3.2. Experimental dataset

The KBS LTER core database's soil moisture and temperature data are used to simulate the smart agricultural system for automated irrigation and fertilizer treatment. The dataset consists of real sensor readings with the appropriate treatment labels. The dataset contains seven attributes, which are detailed in Table 1.

Table 1. Dataset description

Variate	Description	Units
Year	Year in which sampling data occurs	
Sample date	Sampling date	
Trt	Treatment	
T0-2 cm	Temperature 0 to 2 cm	Celsius
T3-15 cm	Temperature 3 to 15 cm	Celsius
W0-2 cm	Water 0 to 2 cm	cubic centimeters
W3-15 cm	Water 3 to 15 cm	cubic centimeters

The dataset includes sensor readings from each day over a 10-year period. The dataset has a total of 15706 instances. The dataset attribute that must be predicted is defined in "Treatment Type," which consists of five labels (1, 2, 4, 6, '7 and 8'). For simplicity, we divided the treatment class labels into five categories (0, 1, 2, 3, and 4). The class label is converted using label encoder. Table 2 depicts the sample values for the raw dataset and the class labels. Next, during the data preprocessing step, the 'vdate' attribute is converted into date and time format. During the conversion of 'vdate', we discovered more than one sensor entry per date, but without time stamp. To simplify things, the dataset is grouped by 'vdate'. Additionally, the dataset resampling is performed to calculate mean values of each date. During this process, we also consider the treatment type attribute. Using this resampling, the dataset size and treatment types are altered. Table 3 shows the converted data. The final dataset includes three classes and a total of 3288 instances. The dataset now contains one sensor record for each date, which shows the mean sensor reading for each date. Additionally, the dataset readings are visualized.

Table 2. Dataset samples

	vdate	Treat-ment_type	T0_2	T3_15	W0_2	W3-15
0	01-01-98	0	1.68	1.77	0.02	0.18
1	01-01-98	1	1.77	1.87	0.02	0.19
2	01-01-98	4	1.63	1.72	0.02	0.18
3	31-12-97	0	1.65	1.73	0.02	0.18
4	31-12-97	1	1.76	1.85	0.02	0.19

Table 3. Resampled data according to date

vdate	Treat-ment_type	T0_2	T3_15	W0_2	W3-15
1989-01-01	0	-2.960	-2.860	0.25	0.260
1989-01-02	2	1.984	2.556	0.09	0.210
1989-01-03	2	0.930	1.046	0.02	0.180
1989-01-04	2	4.898	5.004	0.04	0.220
1989-01-05	2	10.176	10.176	0.02	0.176

Figure 2 depicts the visual patterns associated with the dataset attributes. The x-axis shows the date, while the y-axis shows the corresponding sensor reading. According to the diagram, soil temperature demonstrates repetitive values at the end of each year. This dataset is then used with the ML algorithm to learn and predict. Finally, the prepared dataset is used to train the ML algorithms that will predict the water and fertilizer treatment plan.

Assumption: to demonstrate the required automated irrigation and fertilizer treatment system, an assumption has been made. In this experiment, classes 0 with fewer samples are considered fertilizer treatments, whereas class labels 1 and 2 indicate irrigation treatments. Moreover, if the predicted label is 1 then its low water treatment required and if label is 2 then soil is dray and high-water treatment is needed. This performed by using label encoder.

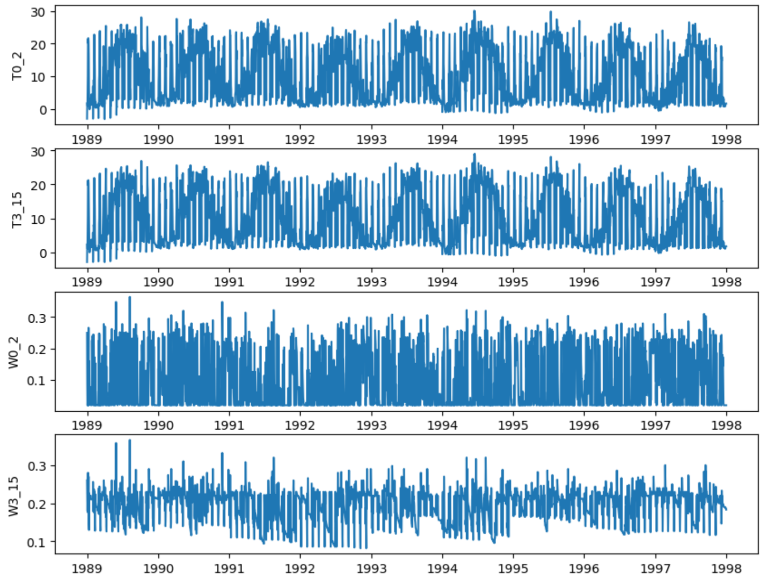

Figure 2. Date wise sensor reading and variation

3.3. Machine learning algorithm training

The prepared data can be used to train ML algorithms. Additionally, the water treatment plan or fertilizer treatment plan can be predicted based on instant sensor readings. In this case, a deep neural network (DNN) was trained to perform classification tasks. The deep learning models are much appropriate for large and growing size of databases for accurate and efficient data analysis. The implemented DNN has the following configuration:

a. The model type is considered sequential.
b. The first layer uses a similar number of inputs as the dataset. Furthermore, this layer employs 128 neurons with the activation function 'ReLu'.
c. The second layer has 64 neurons with the activation function 'ReLu'.
d. The third layer consists of 32 neurons with the activation function 'ReLu'.
e. The final layer includes three neurons that represent the neural network's output.

The above model is compiled with categorical_crossentropy as the loss function and Adam as the optimizer. This configuration is obtained by hit and trail approach. Therefore, different CNN configurations have been implemented and experiments are performed, based on the optimally resulting CNN model's configuration is discussed above. In addition, the accuracy matrix is used for validation. The model has been trained and validated, and the accuracy obtained for both parts is shown in Figure 3. The x-axis shows the number of epochs, while the y-axis shows the accuracy. The results show that the validation accuracy is lower than the training accuracy. The training accuracy varies from 89% to 89.3%. Additionally, the validation accuracy ranges from 88% to 88.6%. As a result, the DNN algorithm provides an acceptable level of accuracy. This DNN model is being used in subsequent decision-making processes.

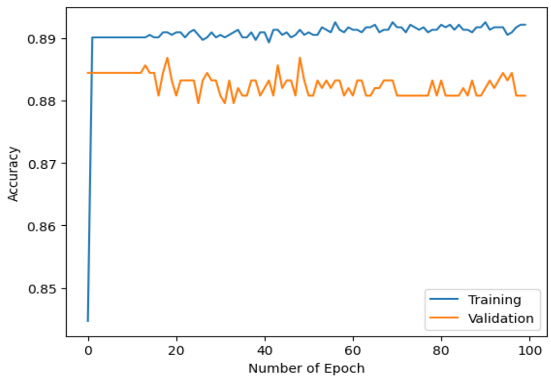

Figure 3. Training and validation performance of implemented ML algorithm

In addition, the performance of the model in terms of precision, recall and F-score have also been measured. In addition, the comparison of the applied DNN method has been performed with two popular ML algorithms namely support vector machine (SVM) and random forest (RF). Here, the DNN is used as the proposed algorithm and SVM and RF is used for comparison. Because both the algorithms are frequently used in classical classification problems. The class wise performance of all three ML algorithms is demonstrated in Table 4. According to the given results, the proposed model is providing more accurate classification results as compared to other two classifiers.

Table 4. Comparative class wise precision, recall, and F-score

Classes	Precision			Recall			F-score		
	DNN	SVM	RF	DNN	SVM	RF	DNN	SVM	RF
0	0.85	0.67	0.81	0.85	0.69	0.83	0.85	0.68	0.82
1	0.88	0.77	0.78	0.87	0.75	0.77	0.87	0.76	0.78
2	0.92	0.79	0.83	0.94	0.81	0.80	0.93	0.79	0.82

In addition, the confusion matrix of the presented DNN based classifier is also presented. Figure 4 shows the confusion matrix. That is a table, which shows the actual and predicted class labels produced by the classification algorithms.

However, the model provides the acceptable level of classification correctness, but the performance of the model can be optimized using fine-tuning of the model. In addition, the dataset is slightly imbalance but not highly imbalanced, therefore, model is also needed to be train on balanced dataset to avoid overfitting of the model.

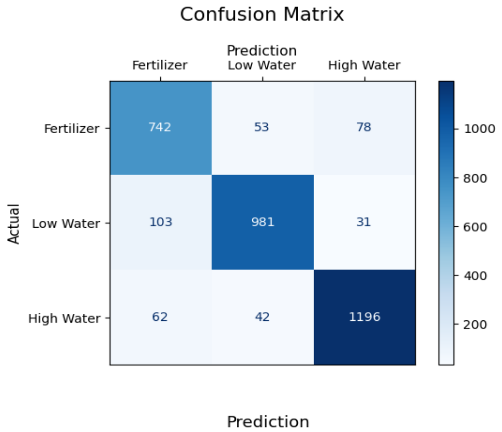

Figure 4. The confusion matrix of DNN based treatment prediction

3.4. Decision making

In this section, we will explain how the proposed model is being used to serve a group of farmers while minimizing implementation costs. However, it is critical to successfully implement this concept for multiple farmers in a collaborative manner. Assume we have a group of N farmers $F_n = \{F_1, F_2, \dots, F_n\}$. The shared infrastructure includes a common water storage (W_s) and a shared fertilizer input unit (F_r). The water storage and fertilizer unit are connected to a dynamic supply enable and disable valve. The valves are controlled by instructions received from the cloud server. The cloud server includes a ML algorithm that is trained using historical sensor readings and the appropriate treatment plans. In this scenario, sensor nodes must be deployed to collect data from various farmer's farmlands. As a result, a sub-network must be established on each farmer's farmland. Farmers F_n include sub-networks $S_n = \{S_1, S_2, \dots, S_n\}$. These sub-networks are comparable in number to the number of farmers involved in this shared smart farming infrastructure. The subnetwork is made up of IoT-enabled sensor nodes. These sensor nodes collect soil characteristics such as temperature, water content, and soil composition. Additionally, any changes in readings are sent to the cloud server. However, each farmer's farmland may contain a different number of sensors and complex locations. Assume each subnetwork contains m IoT-enabled sensor nodes $I_m^n = \{I_1, I_2, \dots, I_m\}$. Furthermore, these nodes are linked to a similar number of valves that control water supply and fertilizer. The steps for enabling and disabling valves in a specific location are as shown in Table 5. According to the algorithm steps outlined in Algorithm 1 the server is running a continuous process. This process is currently waiting for readings from the shared infrastructure. As new readings appear, the algorithm determines the sub-network id and sensor node id. The sub-network id is also used to identify the farmer and send the notification. The reading R is then converted to a vector containing various soil properties such as moisture, temperature, and composition.

Table 5. A basic comparison of individual and shared infrastructure

S. No.	Components	Frequency	Unit price	Individual	Shared (FOR 3)
1	Moisture and temperature sensor	One time	500	500	500
2	Wi-Fi network and internet	Monthly	2500	2,500	2,500
3	Pipeline	One time	30/Mt	30	30
4	Valve	One time	530	530	530
5	Water storage	One time	1 L	1, 00, 000	0.33 L
6	Fertilizer storage	One time	1 L	1, 00, 000	0.34 L

	Basic comparison of the cost of individual and shared infrastructure.			2, 03, 560	70, 560

Algorithm 1. Proposed algorithm for automating irrigation and fertilizer treatment

Input: Sensor Node Reading R, Sensor Node ID ${I_m}^n$, Trained ML Model T_R
Output: Instructions [valve type, target valve]
Process:
1. For each New Reading R
   a. $[Subnet,\ snNode] = Identify({I_m}^n)$
   b. $[Moist, Temp, Comp] = GetReading(R)$
   c. $O[0,1,2] = T_r.Classify(Moist, Temp, Comp)$
   d. $If(O == 0)$
      i. $Valve\ type = Enable\ Fertilizer\ Valve$
   e. $if(O == 1\ ||\ O == 2)$
      i. $Valve\ type = Enable\ Water\ Treatment$
   f. $else$
      i. $disable\ valve$
   g. End if
   h. Send message to farmer F_n
   i. target valve = Enable Valve of $[Subnet,\ snNode]$
2. End for
3. Return Instruction [valve type, target valve]

These properties serve as input to the trained ML model. The model generates an output with the values 0, 1, or 2. Depending on the generated output, the valves are enabled or disabled. Furthermore, the obtained instruction is sent to the farmer as a notification, and this message is also sent to a specific IoT enabled node to enable the valve.

4. IMPLEMENTATION

In this section, we will discuss how the proposed concept can be used to create a low-cost smart farming (LCSF) Infrastructure in a shared environment. The proposed system can be implemented using a layered architecture, as shown in Figure 5. The layers and their details are described in this section.

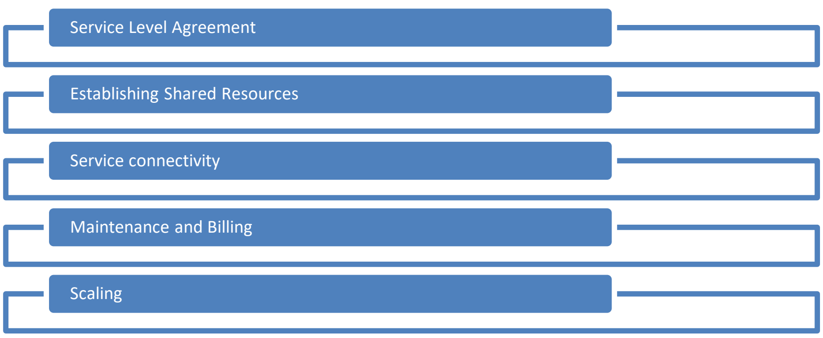

Figure 5. Layered architecture to implement proposed system

4.1. Service level agreement

The shared techniques serve a specific community. Furthermore, utilize and establish cooperatively. To become a member of this community, you must sign a service level agreement (SLA). This service agreement includes the terms and conditions. These terms refer to the following aspects: initial contribution to establish resources, time of service, conditions of service, maintenance and billing, and service renews terms.

4.2. Establishing share resources

The establishment of water storage and fertilizer storage units incurs significant expenses. Furthermore, hiring a cloud server incurs both initial and ongoing costs. These expenses are borne by the community using funds collected through SLA and government subsidiary schemes. In addition, the SLA-secured fund is used to manage other related activities.

4.3. Service connectivity

The entire LCSF system provides service under shared conditions. As a result, the services are provided in a plug-and-play manner. Anyone can join or leave the service based on the SLA. However, the LCSF model requires the establishment of a sensor network and irrigation valve system. If the available funds are sufficient and the community is willing to provide rental hardware, the service connection will be available. Otherwise, hardware resources at the farm are determined on a personal basis.

4.4. Maintenance and billing

The server houses the software system. The server runs the decision-making service and also uses a billing system for maintenance. The sensor readings change, and the decision-making module responds. Before sending instructions to the sensor, water storage, and/or fertilizer storage unit, the algorithm reveals the farmer id and sends a notification. The generated notification may also include the amount of water and fertilizer delivered to the target valve. This amount of water and fertilizer is converted into a billable amount. As a result, the system can also manage billing in order to maintain services.

4.5. Scaling

The cooperative nature of the proposed shared LCSF system allows anyone to join or leave the service. The SLA defines the service time frame and conditions. Additionally, the entire infrastructure operates on a plug-and-play basis. The user can connect to the service, use it based on their crop needs, and pay the bills like any other utility bill. As a result, the proposed model significantly lowers the initial and ongoing costs. The proposed model is also appropriate for farmers who are hesitant to adopt smart farming technology due to the high initial and ongoing costs.

4.6. Cost-benefit analysis

The establishment, execution and maintenance all requires a significant amount of funds. That is a basic cost estimate which shows a rough estimate to establish first time the entire system. Here we can see the entire cost is more than 2.03 L, but when the farmers are utilizing the shared infrastructure than they can save the money not only during the establishment as well as during the execution of the entire system. The bills and maintenance can also be split into the program partners.

4.7. Integration with government schemes

The government has a number of policies and schemes, where they assisting the farming projects. In addition, the government also providing credit line based on their farmland. Therefore, government needed to discuss and aware the farmers for this shared approach of farm irrigation. The similar concept can also be utilized in other critical issues of farming like disease detection, harvesting, and monitoring. This concept can fit for startups to develop a business idea with involving shared infrastructure.

5. CONCLUSION

Food and water security are issues of human sustainability. As a result, improving farming methods is critical for increasing productivity and quality in order to meet needs. This paper presents a highlight based on recent literature to optimize and improve the agricultural process. Using this literature, the role of ML, sensors, and networks in agriculture was investigated. Furthermore, a ML process is discussed to demonstrate how sensor data can be collected and used with ML algorithms for decision making. Next, the ML-based algorithm is used to simulate the process of a shared low-cost smart farming application. This allows farmers to establish and maintain smart farming infrastructure at a low-cost. Additionally, the basic components of the required model are discussed. The proposed work will help to motivate farmers to build and maintain a community smart farming infrastructure. In near future, the proposed can be extended for the following future directions: i) create a real-world experiment or pilot deployment for real data collection and experimentation and ii) however, some sensors and hardware suggested, but need to explore more for reducing the deployment cost.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this research paper. The authors declare that they have no financial or commercial relationships that could be construed as a potential conflict of interest. The authors declare that there are no personal, professional, institutional, or financial conflicts of interest related to this study.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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