International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

IoT and Big Data Framework for Paddy Cultivation

N. Revathi, P. Sengottuvelan

Abstract: ***Agriculture needs agriculturists to adopt digital in terms of low cost data acquisition from Soil, Weather and water related resources through drones, satellites, sensors and weather stations where in data sources are different, unstructured, volume and veracity of data generated is also huge which poses as a big data problem to solved. Agriculture is the backbone of India and being the largest paddy producer in the world. TamilNadu alone contributes at 7% of the overall paddy cultivation. The key aspect of TamilNadu paddy cultivation is 90% of its farmers belong to the small and medium size category. It's important for farmers who are producing paddy to be equipped with the technology advancements in a simple and effective manner to manage better way of irrigation in terms of water management, improving yield and efficient use of fertilizer and pesticides. Due to inherent nature of large area involved and complex eco system involved paddy cultivation have been always posing challenges in new technology adoption in terms of data acquisition, processing and reporting and lacks easy to follow contextual framework technologists to adopt. This paper would discuss on the infrastructure, technology and big data aspects for paddy cultivation by qualitative research methods. The research would involve identification of the appropriate contextual framework through architectural means and algorithm which would help in sensor deployment strategy. At the end the paper would develop a framework for approaching the IoT and Big Data in paddy cultivation. The framework would outline the architecture components, protocols, communication interfaces which could be leveraged for paddy cultivation. Apart from this the framework also discusses the Wireless sensor network deployment and its key aspect such as coverage in the paddy fields.***

Keywords: IoT, Big Data Framework, WSN, Sensor Networks, Paddy cultivation, Farming

I. INTRODUCTION

As per the report's food demand will increase in the coming decade. Agriculture contributes to 16% to GDP and up to 10% of total exports [1]. Paddy cultivation is one of the essential occupations in southern part of India. India being one of the largest producers of rice and it contributes up to 20%. There is always a significant need for improved distribution of the rice through improved infrastructure such as Rail, Roads and Rural Electrification [2].

Revised Manuscript Received on 30 July 2019.
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Paddy cultivation being more labour intensive an incremental raise in the wages of the labour would have negative impact on overall margins and revenue of the paddy farmers. Technology is becom0ing the prime mover of the agriculture in the recent times. There has been a steep increase in the adoption of Sewing machines, harvesting machines in the paddy cultivation.

External factors such as weather, ecosystem including water, soil, etc., would be affective the overall growth of the paddy. In paddy cultivation water consumption, spends on pesticide and insecticide, potential reduction of labour wages in paddy cultivation through technological advancement such as IoT and Big Data is always welcome. Due to global warming by 1°C there is potential yield losses expected in agriculture[2].As adoption of IoT is growing with cheaper cost of Sensors, increased accessibility of external data, lower storage costs, low cost telecommunication networks enhance the climate of such adoption. Embracing technological concepts such as IoT and Big data would certainly help to be more precise in paddy cultivation and thereby improving larger picture of paddy cultivation in India. Government of India has opened the Kisan centre data set for analyzing the data for further research.

II. EXISTING LITERATURE

Typical paddy cultivation in India would be grown within the period of 3-6 months depending upon the selection of type of rice cultivated. Typically, this would undergo the following steps: 1) Germination 2) Vegetative State 3) Reproductive state and 4) Ripened state which would happen on the field, nursery and again on the field as given in the Figure 1 given below:

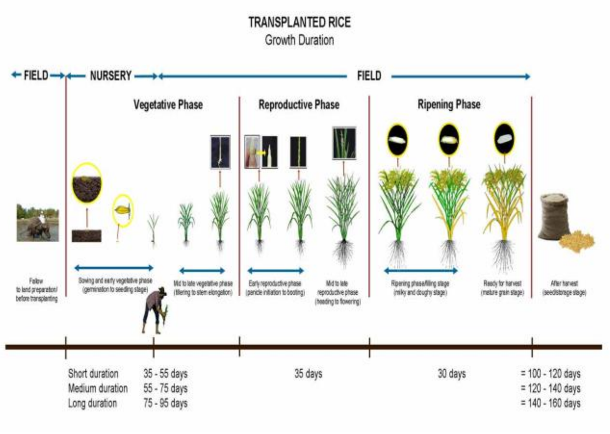

Figure 1: Source International Rice Research Institute

Adoption of agriculture for IoT has been discussed as Smart Agricultural solutions [3], Crop disease identification using embedded systems [4], etc., recently. The paper on smart agriculture discusses on potential usage of underground communication interfaces, sensors adoption and need for data aggregation. Finally outlines that the problem of large scale and interconnected nodes being a major issue in these kinds of implementation.

It’s very essential to establish low cost remote sensing and monitoring solutions with respect to agriculture related implementations. Technologies like LORA could be helpful in such scenarios. The recent advancements and trends paper [5] discuss on adoption of Wireless Sensor Networks (WSN), different platforms including Node MCU, iMote, etc., Wireless technologies (Wi-Fi, Bluetooth, etc.,).Also, it provides insights on the agriculture related applications of IoT including Open Field agriculture, Food supply chain, Controlled environment agriculture and Agricultural monitoring and control. It concludes that Security, involvement of large ecosystems, anonymity of data collection to be part of appropriate strategy for such an implementation.

Considering the vast fields of paddy cultivation, it would be also complex from an infrastructure stand point of implementing WSNs. A paper[6] on monitoring of crops discusses the adoption visual sensors. Discusses on adoption of image processing for identifying the crop diseases based on the visual output of the farm fields to identify trends and potential problems in terms of crop diseases.

Usage of big data to reduce the pesticide usage in order to reduce cost of farming and improve the quality of the soil discussed [7] by evaluating aspects like production by crop, production by area, etc., The paper also discussed about big data map reduce algorithm for determining the crop demand.

Since the nodes deployed in farmland are potential candidates for security attack it’s important to secure the data sources through intelligent perception of intrusion detection. In the paper[8] on the topic of neural network adoption and traditional ARIMA kind of techniques with respect to improving security in farm land considering the volume of data potential vulnerability due to multiple sources of data and higher scale of data.

WSN deployment for Paddy cultivation in the Kerala area, Kuttnad[9] has outlined the usage of Zigbee for the paddy field monitoring. This outlined the different states of the WSN deployment including sleep, monitoring and its appropriate energy conservation approaches.

Concepts of Smart farming have been there for a while, Smart farming implementations and its learning has been also discussed[10]. Discusses on the sensor-based data acquisition, ingestion and visualization. The discussion has not been specific to paddy cultivation but it’sbeing discussed in general.

III. PROBLEM STATEMENT

Despite lot of efforts are being made by the farmers, technological advancements are helping them to optimize issues. Some of the general problems for farmers in managing the steps of paddy cultivation effectively are provided below:

1. General issues:
   - Vast fields and shortage of labour
   - Higher labour costs
   - Managing the ecosystem effectively to minimize impact to crops
   - Minimizing impact from natural calamities
2. Specific Issues:
   - Effective weed management – Might have an impact on Eco System as well
   - Effective water management – In Paddy water consumption would be higher
   - Effective pesticide management – Need to look at Bio diversity
   - Harvesting – Minimize waste, improve straw-based revenue
   - Simplified Storage and distribution management

The problemabove stated is combination People, process and technology. These kinds of problems can be resolved with focus by working on the areas of collection of data, arriving at insights and acting upon them. The advent of technological concepts such as IoT and Big data can help the farmers to a greater extent. Existing solutions (

Figure ***2***) only revolve around the areas in very generic mannerand sometimes adoption of the same to Paddy cultivation becomes a problem

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DOI: 10.35940/ijrte.B3611.078219
Journal Website: www.ijrte.org

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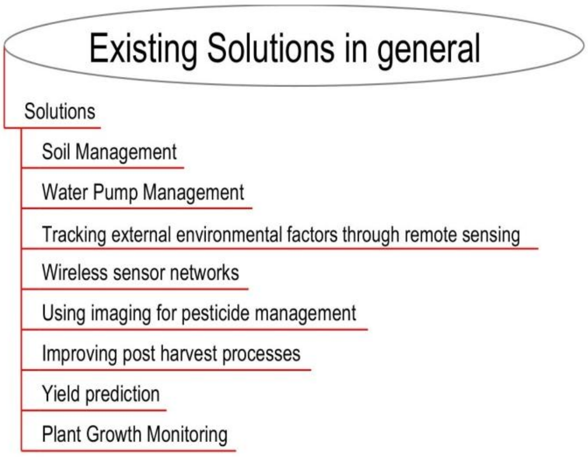

Figure 2 - General research solutions available

There has been lot of discussion around the areas of implementing IoT and Big data but in general there is a lack of well-defined conceptual framework for bringing guidelines for the research enthusiasts to pursue in a specific direction which would help paddy farmers. The goal is to identify the variables which would be constituent to the framework which would have a generic implementation approach and would guide future development.

Key factors for consideration:

The generic framework which is to be developed would have different technical challenges as outlined below:

1. Large volume of heterogeneous data to be collected from the sensor from the field
2. Data ingestion with different set of communication networks
3. Need for leveraging BYOS (Bring your own sensor) kind of model for leveraging existing systems and optimizing cost preferences as per the farmers need.
4. Integrating heterogeneous data collected from different sources for obtaining unified single source of truth from data
5. Integrating the data insights based on unstructured data from other ecosystems to determine demand, weather conditions, availability of agricultural tools and equipment's.

As the prior knowledge[11] of the problem always helps in building a framework in appropriate ways the utilization of the existing solutions with various IoT Platforms[10] gives us a generic sense of potential framework for Paddy cultivation monitoring and analytics.

Questions to be answered by the conceptual framework:

1. What are the layers of the solution?
2. What are the non-functional aspects the framework should address?
3. How the security to be layered as part of the solution?
4. What are all the existing solutions which are being adopted which would help to better the
5. Overall solution?
6. How the solution components to be composed and architecture?

Sno#	Type of Sensor	Application
1	Water Level Sensor	To determine the spread water or water level in the paddy field
2	**Low power image** Sensor	Setup in the pest traps can help in determining the volume of pests and then it can help the farmers appropriately
3	**Noise sensors**	Can record the noise level of insects and pesticides which can be helpful in determining the trends and patterns. This would help in identifying the increasing trends and help on understanding the balance in the farming ecosystem.
4	**Optical Sensors**	Optical Sensors can be helpful in determining the Leaf Area Index(LAI) which can help in understanding the effectiveness on photosynthesis processes.
5	**Hyperspectral Sensors**	Adoption of Hyperspectral sensors along with drones can help in thermal imaging and detect problems in early stage of the paddy growth to take preventive measures
6	**MCPs With the help of Multiple Capacitance Probes(MCP)**	It can help sense volumetric water content (VWC), temperature and conductivity directly helping in determining soil moisture level and planning irrigation.
7	**USD Ultrasonic Distance Sensors**	Leveraged for determining the measure of water depth. This can help in determining the level of underground water available from water tables.

7. How to arrive at common terminology and concepts for the implementation of the
8. Framework?
9. How do we go about the deployment of WSN?

IV. FRAMEWORK DEVELOPMENT

The framework which we intent to develop would eventually evolve as implementable platform with a combination of IoT and Big Data analytics very specific to Paddy cultivation. When there are numerous platforms available in generic for different use cases, this research focuses only on the framework focusing on the paddy cultivation alone. It considers the wireless sensor node related deployment as it would be essential for effective monitoring.Areas which need focus from paddy cultivation standpoint in terms of aspects outlined would revolve around the following technical areas in terms of architecture [12]:

- Security aspects
- Selection of Sensors
- Adoption of Flow meters
- Data gateway selection
- Protocol needed for communication
- Communication Networks
- Data Ingestion aggregators and gateways
- IoT Platform

- Field Gateways
- Data Lakes and Data Analytics
- Data Visualization
- Middleware Environment
- Authentication and Authorization

A. Design consideration

Design choices of overall communication infrastructure for paddy cultivation is essential. There is a need for determining the communication network, protocols to be used, data aggregation methods. Any design mistakes could prove costly. The below given diagram provides the design choices(Figure 3: Design choices as a reference.)

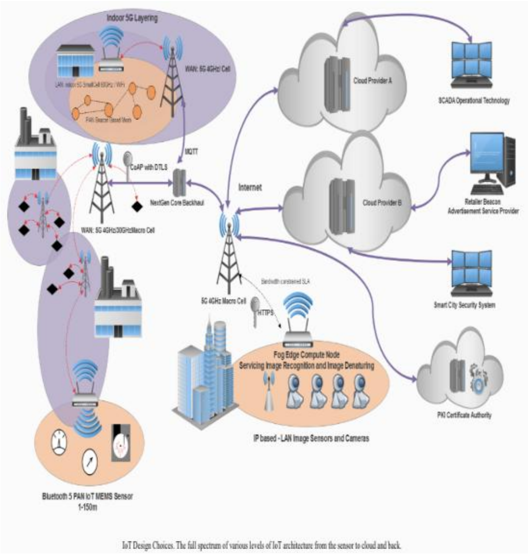

Figure 3: Design choices

B. Wireless networks Wireless networks needs to be established in terms of the large fields as they would be essential for communicating the sensor data. As per the Robert Metcalfe law the value of any network is proportional to the square of connected users of a system. For determining the value of the network for the device i on the network j, we

can leverage the Beckstrom's law as given below given

C. Equations

$$\sum_{i=1}^{n} V_{i,j} = \sum_{i=1}^{n}\sum_{k=1}^{m} \frac{B_{i,j,k} - C_{i,j,k}}{(1 + r_k)^{t_k}}$$

Equation 1

Sensors and applications

Low power low maintenance wireless sensor networks would be essential for large paddy fields which run into acres and hectares. These wireless sensors networks should consume less power, scalable and adaptable as well. The table(**Error! Reference source not found.**) given below outlines the different set of sensors needed for the Paddy cultivation related applications[13]

Flow meters:

As water being one of the critical aspects of paddy cultivation. Enough mechanism to be in place for effective water management. Typically during the planting process from the nursery the paddy field would be flooded with water varying up to 5 to 10 cm after transplantation till 2 to 3 weeks

Before harvesting.

We can leverage the Water Use Efficiency (WUE) [14][15][16]can help to determine the efficiency water being utilized for the field. The utilization of water efficiently could be categorized as Water lost because of transpiration or evapotranspiration or amount of water being consumed through irrigation and precipitation. Formula for determining the WUE is as given in below equation (Equation 2: WUE Formula) :

Equation 2: WUE Formula

$$\text{WUE} = \frac{\text{Crop Yield (Kg/Acre)}}{\text{Irrigation Consumption and Precipitation (m3 /Acre)}}$$

Accurate WUE can be calculated only if we get to the correct information about the crop yield and consumption data. If the fields are using flow meter and appropriate delivery mechanism of water to the fields through pipes the flow can be installed through flow meters, when the water is flowing through existing canals and field-based canals it would become challenging.

Data Gateway:

Data gateway can be based on the 4G/5G cellular or it can be based on wifi or any other communication channel. There has been GPRS based gateway implemented based on WSN. This selection of gateway must be focussed on Maximum distance which can be covered, Gateway power consumption, and Date storage and networking speed.

IoT Platform:

IoT platform could be either of AWS, Azure, GCP or IBM which would be easy to leverage big data analytics. The capabilities of IoT Hub like implementations would help to implement MQTT kind of protocol implementation along with IoT based rules like IFTT. Adoption of the IoT Platform these cloud providers can be scaled and take care of the security needs.

This would also enable integration capability with other services like Streaming, Machine Learning and Deep Learning Capabilities.

Data Lakes, Data Analytics and Data Visualization:

There existing data platform such as MySmartFarm, Pheonet, FarmLog, Dataflag, Farmeron can be leveraged.There are Landsat 8 kind of datasets which can be leveraged for benchmarking. The opensource tools and APIs can be leveraged for the same.

Wireless Sensor Node Deployment

As part of the framework development the very important aspects of the data collection and aggregation is Wireless Sensors networks. If these are not deployed right, it would be immensely difficult to determine data from the Region of Interest.

In the large agricultural land where in there are spatial and temporal differences it would be difficult to capture all the parameters through the Wireless sensor network. So,it's very important to determine the Wireless sensors networks is adequately taking care of the parameters such as Coverage, Connectivity, Cost and Network lifetime[17]. The mode of Wireless Sensor network deployment between Star, Mesh and Hierarchical also a key factor to be decided. It's essential for the WSN to be self-healing and self-forming with ad hoc capabilities.

In a given land, its important that the sensors are capturing the data on the Duty time in order to save energy and time. When these sensors deploy in different spread across the agricultural region, we should minimize the utilization to conserve energy[18]and need to ensure no duplication of data being captured from overlapping regions. At times when there is no need for the sensor node to go to sleep mode or power saving mode and restore its power when needed, this can be determined by heuristics which can help select Wireless sensors nodes mutually [19].

Considering the agricultural area, the sensor network deployment strategy would go as deterministic sensor deployment strategy. In the case of deterministic sensor deployment, the sensor components are placed in a specific, pre-determined locations. Its important the coverage and connectivity are optimally managed. For example, the soil moisture sensor network can be determined based on the geostatistical analysis[20].

For constructing a connected sensor network each region is covered by distinct sensors. When the sensors are stationary, and region is covered by specific radius. The sensors can directly communicate with the sensors based on fixed communication graph. The potential problems can be outlined here in the **Error! Reference source not found.** given below where in any failure in the Sensor nodes S4 and S8 could cause problems in terms of Coverage and connectivity.the Sensor nodes S4 and S8 could cause problems in terms of Coverage and connectivity.

Wireless Sensors Node Deployment Algorithm Pseudocode:

BEGIN

INITIALIZE

Initializing the set of the grid points in the farm land

F ← [f1, f2, f3,…fn]

Points covered by the sensor nodes using Coverage constraints based on the cartesian co-ordinates of the given sensor deployment

$C(S_i) \leftarrow \sqrt{(s_x - f_x)^2 + (s_y - f_y)^2}$

$S \leftarrow \emptyset$

WHILE$F \neq \emptyset$

#Randomly place the sensor nodes to maximize the sensor node coverage

A. $s_i \leftarrow |C(s_i) \cap F|$

B. $P \leftarrow P - C(s_i)$

$S \leftarrow S \cup \{S_i\}$

END WHILE

RETURN S

The Wireless Sensor nodes are typically deployed in the paddy field to maximize the coverage they are deployed based unit disc graph model[21][22]. The above algorithm is implemented based on greedy algorithm[23]. In the initial stage the F is defined the points which would be available part of the grid in the farm land. $C(S_i)$ represents the points which would be covered by the sensor nodes across the grid. Initially the S is set to empty which would be typically the position of sensors nodes. During the deployment process the Sensor node s_i is deployed at the intersection of the field area which would be covered by s_i and uncovered in the field by a maximum. If there larger

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DOI: 10.35940/ijrte.B3611.078219
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Security Layer	**Data Privacy and Integrity Layer**	**User Experience Layer**	Alerts & Notification over smart and Non-smart devices	Administration of Farming Rules and management of Sensor networks and Edge Gateways	Data Visualization	Integration to Ecosystem(s)
		Data Abstraction Layer	Microservice(s) based architecture for exposing to ease of data consumption and addressing separation of concerns exposed through REST APIs			
		Big Data Processing	Leverage cloud or distributed data from Remote Satellites	Machine learning models will be trained continuously based on the data collected from the Edge Processing Layer	Data collected from devices would be ingested using Big Data storage with Timeseries as required along with the Metadata	
		Edge Processing Layer	Run models on prediction based on Environmental factors (E.g., Weather, threats)	Processing Edge Gateway rules based on predefined thresholds, data acquisition intervals etc.,,	Obtain/Push over the air updates on the business rules for effective device management	Fusion or aggregate field data with Sensor data if there is a need for HMI or GPS based info
		Data Acquisition Layer	Environmental Factors	Wireless Sensors Node	Business or Farming rules deployed on to Data acquisition devices	External Field Visit data

Table 1. Contextual Framework

number of uncovered area found the algorithm will randomly choose one. Subsequently the covered points would be moved out of F and the position of the Wireless sensor node will be added to S. This is iterated till we make F an empty set. By doing this the deployment of wireless sensor nodes would be done effectively.

The sensing and communication range are determined based on the unit disc model graph. When there is a problem with the Sensors coverage across due to timeslot of gaps between the sleep and wakeup mode in the field, which essentially leads to deployment of relay nodes. Based on the coverage constraint determination the relay nodes defined as $D=\{d_1, d_2, d_3, d_4, \ldots, d_n\}$. The sensors nodes are always covered by these relay nodes for effective coverage with the given Radius R_d.

Relay node deployment pseudo code is outlined here:

BEGIN

INITIALIZE

Obtain the inputs of Sensor Nodes as S

Set of Sensor nodes covered by the relay nodes di

$C(d_i) \leftarrow \sqrt{(s_x - f_x)^2 + (s_y - f_y)^2}$

$D \leftarrow \emptyset$

WHILE $S \neq \emptyset$

Place the relay nodes to maximize the sensors coverage

C. $D_i \leftarrow |C(d_i) \cap S|$

D. $S \leftarrow S - C(d_i)$

$D \leftarrow D \cup \{d_i\}$

END WHILE

RETURN D

RESULT AND DISCUSSION

Discussion and Results of Contextual Framework of implementation:

Contextual implementation of the Framework discussed has been outlined in the below given **Error! Reference source not found.**. Physical rollout of the Wireless sensor network would be the starting with deployment. Subsequently the data collection or acquisition would start from different perspective to obtain the holistic view of the overall framework. The User Experience Layer, Data Abstraction Layer, Big Data Processing,Edge Processing Layer, Data Acquisition Layer provide appropriate level of perspective in terms data being consumed across the overall system. This contextual framework would revolve more around the Information Architecture than the physical implementation of Cloud, Database, Gateway or sensors nodes.

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Non-Functional aspects of the framework:

Performance of wireless sensors nodes incase of failures of relay nodes ability to communicate needs to be considered as part of the design. Performance of the big data infrastructure to do highly compute oriented modelling based on the Remote Sensing data. This risk can be mitigated by leveraging the APIs available from government institutions. The essential ingredient of notification of aspects like water consumption through non-smart or simplified means would be crucial for farmers to be non-dependant on complex devices.

Security

Sensor node deployment, edge gateways deployment pose as a big threat in the paddy field due to the ecosystem which will attract pests, animals on the field. This would be a major factor for pervasive way of monitoring the field. Even due to human intervention during the field related operations there is quite a possibility of the network and related devices could be disturbed. So more rugged deployment is required in such scenarios.

Big Data Collection

The essential aspect of the overall framework is to collect the big data from the Wireless sensors network. Despite various design considerations of the Wireless Sensor networks such Energy, Quality of Service, Security and Privacy, Adaptability and Localization its very essential to collect the data correctly to provide the necessary service recommendations[24].Various kind of architecture exists to collect the big data which needs to be wisely decided as part of the implementation of this framework for paddy cultivation. Its very evident that without leveraging Big Data tools, framework and associated with programming models, such as MapReduce, solutions cannot process the large amount of data generated by sensors from the Wireless Sensor Networks in the paddy field.

Service Recommendations

As part of the overall framework the components has been decided in such as way the data which has been acquired using the framework can be leveraged to build a service recommendation system for the farmers to take meaningful decision. The service recommendation system[25][26] can be made available through a Web based interface or as an API which can be exposed for the purpose of recommendations for farmers to act upon various issues including Pest Control, Water management and fertilizing etc., Also we can determine the possibility of implementation imaging based analysis based on the height of the paddy crop[27] for right recommendations.

V. CONCLUSION

As part of the work we evaluated various components of the big data ecosystem to develop the contextual framework and its components. In this work we have proposed IoT and Big Data based basic framework by discussing various aspects of problems to be resolved through the contextual framework. Wireless Sensor Network being the core part of the problem domain, we have outlined the necessary algorithm to manage the wireless sensor networks. The framework can be leveraged to aid farmers during crop cultivation toanalyse soil, crop cultivation, and crop diseases and to appropriate recommendation during cultivation. Thus, architects and programmers from technology companies, researchers, as well as individuals who are interested in this paddy cultivation can choose the appropriate framework, based on the key performance indicators they wish to use, in order to analyse data and gain efficient results.With the help of latest technologies like IoT, Big Data, Cloud Computing and Artificial Intelligence. As a future research we can implement the components of the framework for building a recommendation system for paddy farmers based on the big data ecosystem.

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