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A User-Centered Security Approach to Create an IoT Based Multi-Layered Fog-Cloud Architecture for Data Optimization in Raised Bed Farming

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ABSTRACT

Cloud computing and Internet of Things (IoT) are popularly intertwined to create a network of smart systems, especially in the field of Agriculture. As agricultural industries rise, augmented use of heterogeneous communication and sensing on the field would be needed. For all this data to be transferred and processed on the cloud efficiently, low latency rates, consistently high bandwidths, minimal congestion, etc. would be needed, which, is still a complication with the current cloud computing models. This paper proposes a multi-layered fog architecture that detects outliers in the data received from the sensing environment based on three categories: Classification, Isolation, and Clustering and then aggregates it before sending it to the cloud. The architecture works closely in a user-centered design approach that connects the farmers and analysts to the fog allowing them to create an automated agricultural system. With the help of Fog, processing abilities are brought closer to the data source which reduces the load on cloud resources, thereby making the overall system a lot more efficient and secured. This paper also presents a prototype of the interface that can be used to monitor and control IoT devices on the field as well as define fuzzy rules for the agricultural system.

1. INTRODUCTION

IoT is an interconnection of various devices that use embedded technology to sense, communicate, and interact with their internal and external environments [1]. IoT has emerged as a megatrend for next-generation technology that has the potential to impact the entire business sector by providing enhanced connection of end devices, systems, and applications [2].

As a result of the emergence of Industrial IoT, far more advanced sensors are being used in agriculture. A cellular/satellite network is currently used to connect the sensors to the cloud. The real-time data from the sensors allow us to make better decisions [3]. The advancement of IoT technology in agriculture operations has enabled the use of sensors at every stage of the agricultural process, such as how much time and resources a seed requires to mature into a completely grown crop. Every object that can be operated over the internet is referred to as a device [4]. Wearable IoWT (Internet of Wearable Things) gadgets like smart watches and home management solutions like Google Home have made IoT devices very popular in consumer markets [5]. By 2020, it is expected that over 30 billion gadgets will be connected to the Internet of Things. The uses of IoT in agriculture are aimed at traditional farming [6].

Applicability of IoT in Agriculture:

Smart farming is a high-tech and efficient approach to agricultural and food production that is both sustainable and efficient. It's a way of incorporating connected gadgets and cutting-edge technology into agriculture. Smart farming relies largely on the Internet of Things, which reduces the need for farmers and growers to perform physical labor and so boosts productivity in every way possible [7-9]. IoT-based Smart Farming improves the overall Agriculture system by monitoring the field in real-time [10, 11]. Thanks to sensors and interconnectivity, the Internet of Things in Agriculture has not only saved farmer's time but has also reduced resource waste such as water and power. It keeps track of a range of characteristics, including humidity, temperature, and soil, and delivers feedback [12].

Figure 1. Motive of raised bed farming

Robots, drones, remote sensors, and computer imagery, along with machine learning and analytical tools, are also used in farming to monitor crops, deliver data to farmers for sensible farm management plans, saving time and money. Cloud computing has a lot of potential in the agriculture business. By incorporating IT into the traditional farming system, it can be improved. Motive of raised bed farming is shown in Figure 1.

Mocau et al. [8] has proposed a cloud-based infrastructure to supplement traditional farming management systems, which uses cloud-based architecture to monitor farm management. These days cloud computing is an extensively used service across the world, but there are major problems with the clouds. Here we are going to discuss some important problems.

1.1 Challenges and limitations of cloud

These days we can see traffic on cloud environments is constantly increasing becoming a big problem which in turn may lead to network congestion and many other problems [13]. Since Cloud data is accessible through public internet platforms, there are many chances that data is intruders may get easy access to valuable and confidential data of the customers. Even though numerous efforts are being done to secure cloud computing systems from many vulnerabilities and data breaches, but still, it is being a challenging task for IT security professionals. Cloud Service latency is becoming one of the alarming problems [14]. Latency depends upon the geographical location of the end-users where users far away from cloud servers may experience poor services like delay in transmission of data. Without the internet, we can’t even imagine using cloud services. Hence, cloud services aren’t accessible at any internet connectivity locations. And they are highly time-sensitive at poor no internet connectivity areas.

1.2 Transformation towards IoT and fog computing

At today’s pace of technological revolution related to the Internet of Things where many objects need to be connected to the internet and so much data needs to be analyzed and processed [15]. Transmission of all these data to the cloud would be difficult because of the increase in latencies and traffic within the network; this also requires high processing capacity and bandwidth [16]. So, the Fog Computing paradigm shown in Figure 2 is introduced to reduce the above problems by supporting the cloud computing architecture.

Fog computing aims to work on a decentralized approach that helps to reduce data traffic problems in centralized cloud computing [17]. Fog layer is represented by a sensor node and actuators where it uses algorithms to filter sensor data, tasks like cluster analysis, alert management, etc., are performed to reduce the computational load on the cloud [18]. Fog computing can solve many IoT challenges like resource-constraint, latency constraints, IoT security challenges, Network bandwidth constraints, [19]. Fog computing reduces the latencies by performing all computational tasks close to the end-users [20].

1.3 The interface of fog with the cloud and IoT

The fog layer serves as a bridge between the IoT and the cloud. It is responsible to communicate among the two layers and acts as the common interface layer between them as shown in Figure 3.

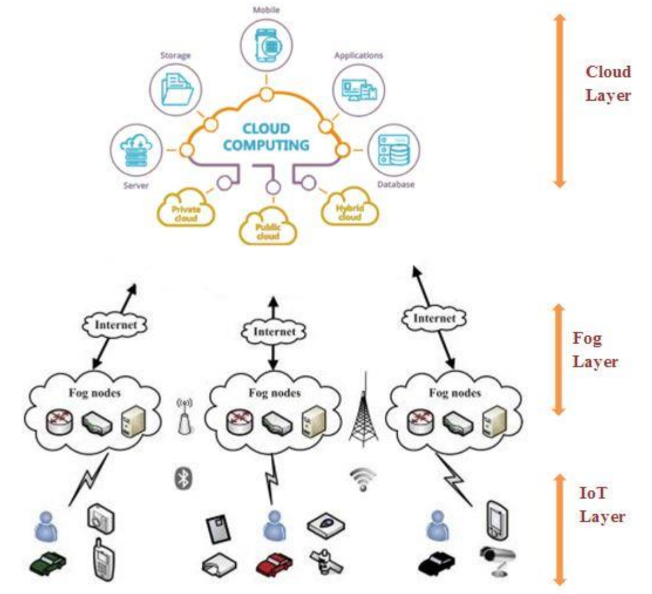

Figure 2. Fog computing architecture

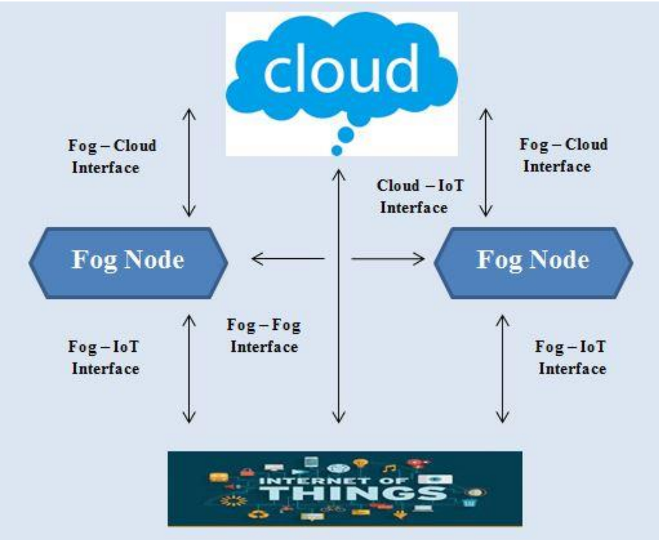

Figure 3. Interface of fog with cloud and IoT

Depending on the type of communication, various types of interfaces are present between each layer such as Fog-Fog Interface, Fog-IoT Interface, Fog-Cloud Interface, Cloud-IoT Interface [21, 22]. The fog layer should be used to hold real-time data that requires quick processing. Similarly, mass storage and computational data that requires a lot of processing power should be stored in the cloud [23]. The difference between cloud and fog computing is given in Table 1.

1.4 Seven-layer fog computing architecture

The seven-layer fog computing architecture contains seven layers as shown in Figure 4. The components are organized into many categories on the basis of their usefulness, that is determined by the layer [24, 25]. These features will allow sensor nodes to interconnect with fog and the cloud [26].

Table 1. Comparison of cloud and fog computing

Parameters	Cloud computing	Fog computing
Latency	High	Low
Real time interactions	Supported	Supported
Mobility	Limited	Supported
Distance between client node and server node	Multiple hop	One hop
Proximity and geographic coverage	Global	Local
Target users	Internet users	Mobile and resource constrained users
ssTransmission	Device-to-cloud	Device-to-device
Resource management	Centralized/Distributed	Centralized
Location Awareness	No	Yes
Location of Service	Within internet	At the edge of local network
Security measures	Defined	Hard to define
Deployment	Centralized	Distributed
Distance to end devices	Far	Near
Connectivity and communication	IP-based only	IP and non-IP
Nodes	Servers	Servers, switches, gateways, access points, Routers
Bandwidth required	High	Low
Content generator	Human	Sensors and devices
Magnitude	Data center	single server to a micro-data center
Infrastructure	3 models (PaaS, IaaS,SaaS)	Flexible
vulnerability	High probability	Very low probability
Deployment cost	High	Low

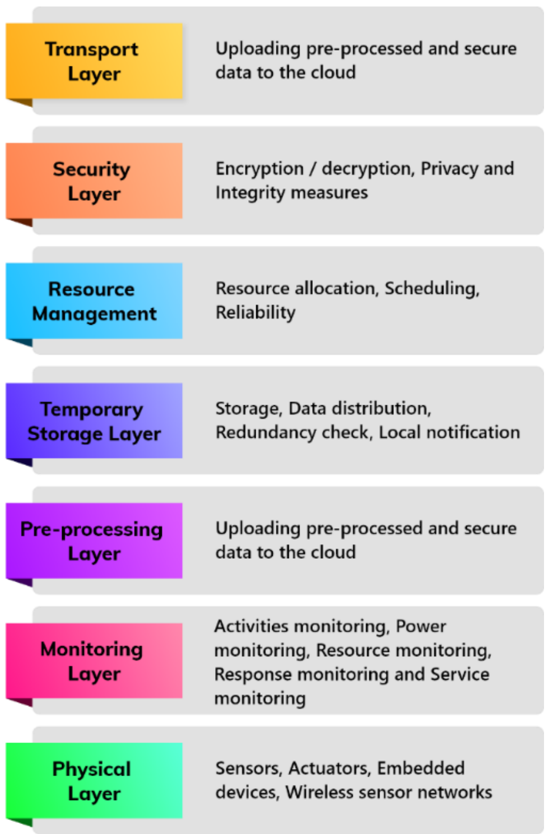

Figure 4. Layered architecture of fog computing

Transport Layer

All the data which is pre-processed at the fog level, needs to be transferred to the cloud. The transport layer is responsible for updating all the pre-processed data to the cloud while maintaining security and latency [27]. Due to the efficient pre-processing done at the previous layers, the load on the transport layer is low and as a result quite fast and secure. This layer is additionally responsible for all the computational requirements requested by various applications at the fog level [28].

Security Layer

All security issues, such as encryption and decryption of data that is exchanged inside the layers, are addressed as indicated by the name. To preserve security, all communications between IoT devices and the cloud must be encrypted; the encryption component encrypts all connections from and to IoT devices and the cloud. Fog computing, like cloud computing, was supposed to be more of a utility computing notion [29].

Resource Management Layer

This layer is in charge of allocating resources, scheduling them, and dealing with energy-saving disputes. The layer itself comprises various components out of which one is the reliability component which preserves the consistency of scheduling an application and its resource allocation [30].

Temporary Storage Layer

The temporary storage layer is responsible for storing all the pre-processed data through virtualization [31]. It comprises an information backup component that guarantees the availability of knowledge and reduces the loss of information [13].

Pre-Processing Layer

This layer consists of sub-layers, which works on data analysis pertaining to the respective fog layer. Firstly, all the gathered data is analyzed and filtered, data trimming and reconstruction is done.

Monitoring Layer

The monitoring layer is the one that keeps track of the system's performance and reactions at all times. We can choose the suitable resources during the operation thanks to system monitoring. Most applications run on smart transportation systems which creates a high chance of facing resource unavailability for efficient storage or computation on a Fog device. To tackle situations like these, the Fog device and the servers will reach out to their neighboring devices and components [32].

Physical Layer

The physical layer is made up of all the virtual and physical sensors present in our architecture, where any and every data generation device could comprise any of the groups. This layer is answerable for all the sensing of relevant data before it's forwarded to the other layers.

1.5 Communication protocols

Based on our proposed architecture we require a multi-level communication system that connects Fog computing with cloud and IoT [33]. To connect the various layers of IoT, a lot of different communication protocols are available such as Internet Protocol Version 6 (IPv6), Z-Wave and Near Field Communication (NFC), Low power Area Networks (6LoWPAN), Bluetooth Low Energy (BLE), ZigBee, etc. [34].

The most widely used IoT protocol to connect networks on Fog is ZigBee (IEEE 802.15.4 standard) mainly due to its long battery life and low duty cycle. Networks that run on this protocol use a mesh topological system and mainly operate at 2.2 GHz -900 Mhz unlicensed frequency bands. Sensors deployed within a range of 100-150m are used for farm monitoring and management using Zigbee technology [9]. With the help of protocols like ZigBee data is efficiently gathered from these sensors and transferred to a cloud data center for further analysis [35, 36].

In smart farming, for long-range communications GSM cellular network is also used especially for smart irrigation and environmental monitoring. For the communication between gateways, the MQTT (Message Queuing Telemetry Transport) protocol is considered as the reference standard for IoT communication [37]. MQTT is a messaging protocol suited for working with limited power computing and connectivity.

2. LITERATURE REVIEW

Table 2 summarizes various research works on IoT, methods, devices and models used.

Table 2. Review of research contributions in the area of IoT

Research Domain	Reference	Research Contribution	Method/ Device/ Models used
Environment Monitoring	[38]	IoT based soil monitoring for farming	Wireless sensors
	[39]	IoT for air pollution monitoring system	Gas sensor and IoT
	[40]	smart environment monitoring	Heterogeneous sensors
	[41]	Air quality monitoring	Geomatics sensors and IoT
	[42]	Aqua farming and energy conservation	pH, and temperature sensor
	[43]	Climate monitoring	LoRa technology and sensor network
	[44]	IoT protocols for acoustic monitoring in the marine environment	WSN and IoT
Agriculture Monitoring	[9]	Smart Agriculture	Pest detection, crop status, irrigation, Soil preparation
	[45]	Smart Agriculature	Deep reinforcement learning, machine learning
	[46]	Precision Agriculture	Cloud computing, IoT, edge computing
	[47]	Agriculture	AI, block chain and edge computing
	[10]	Agriculture data analytics	The combination of Data analytics and IoT is enabling smart agriculture.
	[13]	Smart irrigation	Wireless sensor network, sensor node, and irrigation
	[8]	Pest control	For pest monitoring, IoT and deep learning with global and local features are used.
	[12]	Leaf area index	synthetic aperture radar (SAR) images
Air Quality Monitoring	[46]	Detecting Water contamination	IoT and machine learning
	[48]	Monitoring Water quality	IoT with smart sensors
	[30]	Investigation of Water contamination	Big data and SVM
	[27]	Lagoon water	Machine learning and image analysis
	[30]	Water quality	Neural network
	[24]	Indoor air quality	IoT, LoRaWAN
	[7]	Intelligent air quality system	UV light, AI and sensors
	[16]	Air quality characterization	Heterogeneous sensors, AI
	[25]	Air pollution	Gas sensors
	[4]	CO_2 monitoring	IoT and cloud technologies

3. PROPOSED WORK

The proposed architecture contains four layers namely: Things layer, fog layer1, fog layer 2 and cloud platform as shown in Figure 5.

Things Layer

The Things layer includes devices such as temperature sensors, Accelerometer sensors, Asset Monitoring, embedded systems for light, humidity, and moisture. Things are a virtual representation of all of the resources that can be delivered to different subsystems. The devices work on the field to capture and record the necessary data required for automating the system and communicating with Fog and cloud layers. Data captured from this layer is extremely essential for filtering and Outliner recognition that takes place in fog layer 1. At the Things layer, the fundamental communication protocol is ZigBee (IEEE 802.15.4 standard). Due to its powerful battery life and low-cost cycle, it helps us to maintain an efficient latency between the fog layers, and all the data captured by the sensors and actuators are flexibly transferred to the cloud center.

Fog layer1: Outlier Recognition

The data from sensors of our rides bed farming like water sensors, soil sensors, pH sensors of water and soil, electrical conductivity sensors of soil and water, and also the data of actuators are collected and send to the first layer of fog computing [49]. There are chances that these data may contain outliers. These outliers are caused due to some battery damage problems of sensors and false readings [50]. Outliers in the data may reduce the accuracy and may lead to wrong decision-making of the system. So, in the fog layer, we use some outliner recognition techniques which use machine learning algorithms to remove outliers in the data [51]. This helps fog layer 2 in proper status generation and event detection. And finally, that helps cloud computing systems to predict future crop yield and growth. Here we use some well-known methods for outlier detection they are classification-based, isolation-based, and clustering-based.

In the classification-based method, training of a classification model using a dataset takes place. Here we used the Support Vector Machine algorithm. This algorithm determines any instance that is falling apart from the given boundary as an outlier [52]. The isolation-based method concentrates on the separation of outliners from the rest of the data points and won't profile the normal ones. Here Isolation Forest algorithm is used. This algorithm can find the abnormalities in the data. Clustering-based method groups data which is similar to clusters with almost the equivalent behavior [53]. Instances which don't belong to the cluster are determined as outliers [54]. Here we use the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm. This algorithm groups the instances into high and low-density clusters utilizing simplified minimum density level estimation which is based on parameters like distance radius, thresholds, etc. [55].

Fog Layer 2: Resource Management

After detecting and excluding outliers in the data at fog layer 1, that filtered data is sent to fog layer 2. Here in the fog layer 2 temporary data storage, some machine learning processes and communication with the cloud system are done. The data taken from fog layer 1 is temporarily stored in this layer. Then that data analyzed using decision tree algorithms in machine learning. Those results we got from machine learning algorithms help fog layer 2 in event generation and status detection like crop watering alerts about the farm bed regarding water content in the soil, regarding nutrition and pH levels of the soil [56].

Cloud Platform

The data that crossed fog computing layers 1 and 2 reaches cloud services. Here in the cloud platform that data from sensors and actuators gets analyzed using neural network algorithms. And finally, users can get predictions about the crop yield, also suggests users the techniques to improve crop yield and identification of the crop diseases takes place. crop growth and other parameters will be visualized using data visualization techniques and will be shown to the users.

The proposed architecture used 3 different protocols at each layer of the architecture. Zigbee protocol is used for communication between sensor nodes and actuators [57]. LoRa protocol is used in between Fog layer1 and Fog layer2 to send data after outlier recognition [58-66]. And finally for resource management in between fog layer2 and cloud platform we used the MQTT protocol. The process flow of our proposed architecture is shown in Figure 6.

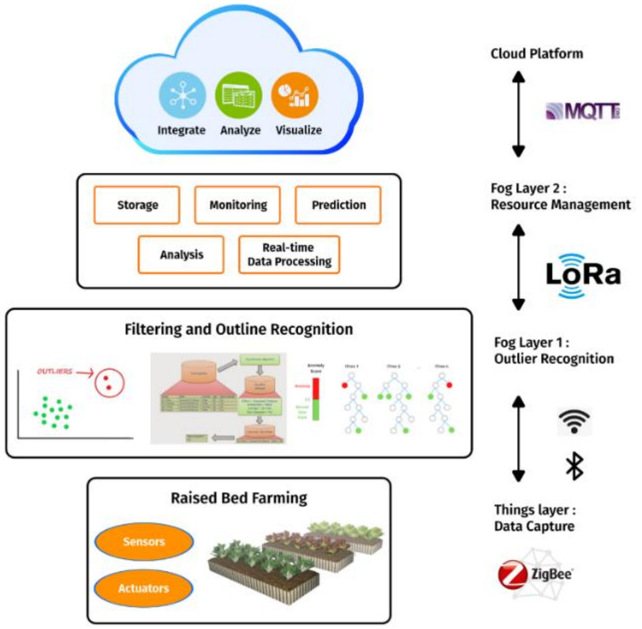

Figure 5. Proposed architecture

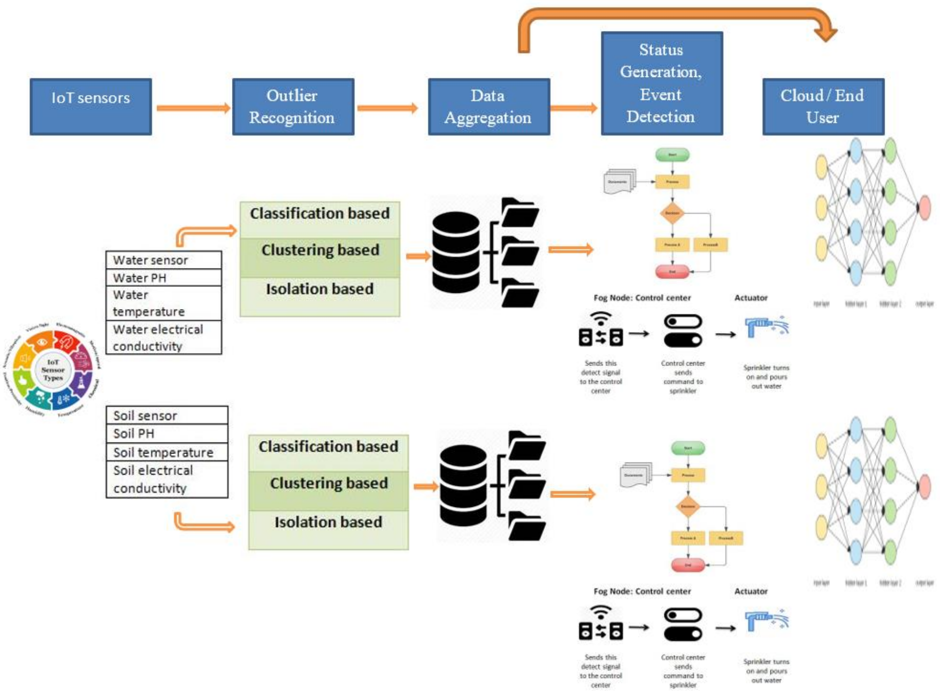

Figure 6. Process flow of proposed architecture

The process flow of our proposed architecture goes on in about 5 levels. These stages work with each other to systematize data between various fog and cloud layers to communicate with the end-user efficiently and seamlessly. The 5 levels are:

IoT sensors: A bunch of sensors of various types is used in the initial stage to sense and record data. Mainly 2 types of sensors are used in the proposed architecture first of which is Water-type sensors are responsible for calculating water pH, electrical conductivity, water temperature. The second is Soil Type sensors which take part in calculating the pH and the temperature of the soil, and its conductivity.

Outlier Recognition: This stage is essential for failure identification and outliers' isolation from correct data. There can be a lot of reasons due to which erroneous results might be generated while transferring data from the sensors to the cloud such as low battery power, loose wiring, etc. It consists of 3 categories: Clustering, Isolation, and Classification. The clustering-based approach uses DBSCAN which segregates the entire dataset into high and low-density clusters [52]. The isolation-based approach uses Isolation Forest (IF) which is capable of identifying anomalies from a dataset it works on the principle of recursive splitting of attribute value trees to isolate data points [51]. The classification-based approach uses a Support Vector Machine (SVM) which helps to identify if any instances falling out of the boundary is a part of an outlier.

Data aggregation: This stage deals with summarizing all the data filtered out from the outlier recognition stage into categories and sections, this is to prepare the data for cloud transfer. The data is also used for Status generation and event detection from which then the data is transferred to the cloud.

Status generation and Event detection: This phase works on the fog node to carry out machine learning processes on different parameters and lets the farmer decide smart irrigation rules to optimize farming. This also returns the status of all the crops in the field. For instance, if the sensors in the field detect low water content, they generate a status regarding the low water in the field and automate the sprinklers to water the crops. Earlier, smart irrigation was controlled by time schedules. Now, with the help of this, it considers data sensors to see if decision trees can be used to optimise watering and growth control. Data is then updated and sent again for data aggregation from where it is sent to the cloud.

Cloud/End-users: With the use of neural networks present at the Cloud layer, all the data from the aggregation layer is sent and processed here for future storage. The result is that only the essential and processed data is sent to the cloud which reduces the latency thereby increasing the speed of data transfer and data processing.

4. PROTOTYPE: USER-CENTERED DESIGN APPROACH

This paper also proposes a new application prototype to provide essential services for the best management of agricultural fields. This prototype involves farmers and analyst as shown in Figure 7.

The motive behind our architecture was to create a system that delivers efficient results and analysis at the same time, reduces work for the users operating it. User-centered design or UCD is a way of defining a design process where the stakeholders (Farmers, Agriculturalists, Analysts) control how the system automates with the fog and cloud layers to deliver data. The process was designed with keeping the users at the core which is why it is essential to create a user-friendly process that the farmers, agricultural specialists, and analysts can trust and understand. The user-centered design approach works based on subjective speculations about the user, their personality, and their behaviour. Sensors, actuators, and the other IoT devices at the things layer perform tasks that automate to optimize production in the field. These devices integrated with other smart devices work to enhance interaction between the user and the fog layers.

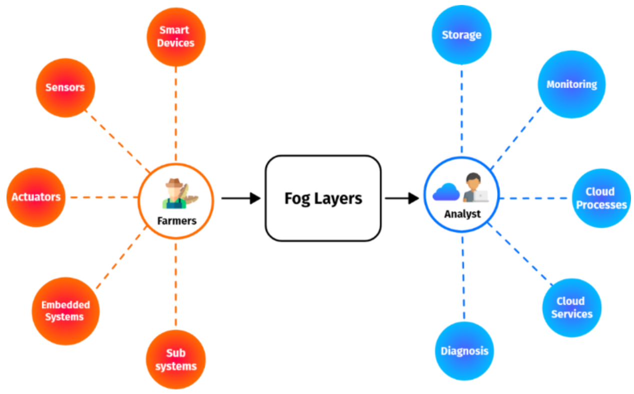

Figure 7. Communication between farmer and analyst

The design approach consists of 2 parts: The first is in respect to the farmers and the agricultural specialists who work in close relation with the things layer. Here the user gets control over how the fuzzy system rules should be defined for the raised bed fields and gets complete control over the sensors, actuators, and the automated equipment. This is done through a smart device present on the farmer's side. The second is based on feedback and results returned after data aggregation. At any point of the day, with the help of various data visualization techniques, the user can get a complete analysis of all the results generated from the fog layers. And based on the results, the rules and settings for the sensors can be adjusted accordingly. Since data from the cloud would also be represented here, data analysts can also take part in controlling or suggesting fuzzy rules for the system. With this approach, we can put the intended users of a system at the center of its design and development. The stages of this process are carried out in an iterative cycle, meaning the entire process is repeated until the project's usability objectives have been achieved.

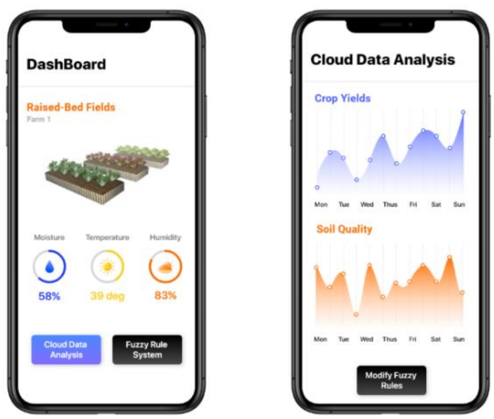

Figure 8. Interface of the dashboard and the cloud data analysis

Figure 8 shows the interface of the dashboard and the cloud data analysis. For the ease of farming and monitoring, an interface that gives out daily analysis and visualization is essential. In the dashboard, critical information such as soil moisture, temperature, humidity is displayed and updated daily. Based on the sensors and actuators configured on the field data is aggregated and the summary is displayed on the screen. Apart from this, the user can also view statistics and visualization of all the crops and their progress over time. As an example, we added a visualization graph for the crop yields and soil quality over one week. With this, the farmer can keep a check on the progress of the crop and can change the necessary fuzzy rules to get better results.

The user stays in control of the entire system throughout the architectural process. The farmer based on data depicted on the dashboard and all the data received can control the necessary sensors and actuators in the field as in Figure 9. The interface allows several various options such as smart irrigation where the user can choose the speed, pressure, and interval of water that the sprinkler shoots. Options like timer and target moisture are also available by which the system automates the need of the user. For example, if the user sets the target Moisture level as 4mm for the entire field, the sprinkler will shoot water till the sensors in the ground detect a moisture level of 4mm or above. Through the use of smart devices, the farmer along with the guidance of agriculturalists can define fuzzy rules for their system. Rules are a form of automated instructions given by the user on how the system should operate.

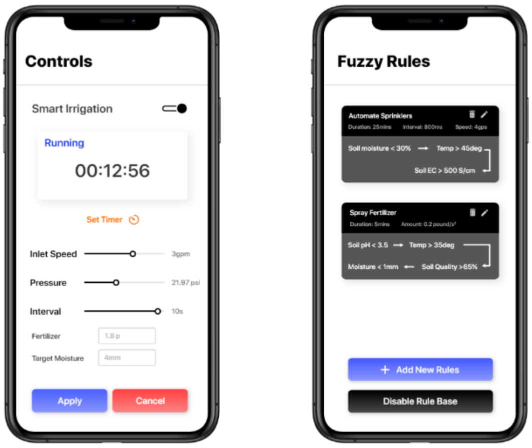

Figure 9. Interface for smart irrigation

If the user needs to automate fertilizer sprays which only activate when met some specific conditions. When the users need to, they can simply add a new rule to the system and disable it whenever they want. The entire prototype of the interface was designed by keeping the users at the center such that it becomes easy for them to grasp and get comfortable with the automated system.

5. RESULTS AND ANALYSIS

Simulation is used to evaluate the usefulness of the proposed architecture. Simulations have been performed in a network composed by fifteen sensor nodes, one gateway node and the Cloud platform. The amount of data stored to the cloud in bytes is evaluated in three different scenarios: Cloud Computing architecture, 1-tier Fog architecture and 2-tier Fog architecture. The amount of data stored to the cloud in one month is shown in Figure 10.

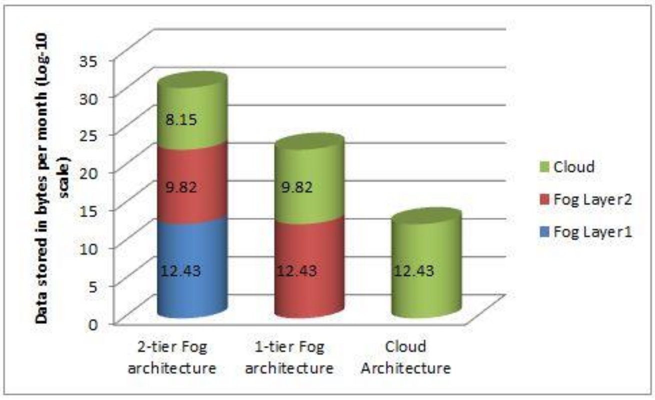

Figure 10. Comparison of the amount of data stored in different architectures

The figure illustrates the decrease in the amount of data stored in the Cloud due to outlier recognition and filtering in fog layer. Accuracy of the three techniques: SVM, DBSCAN and IF, used for outlier recognition is given in Table 3.

Table 3. Comparison of accuracy of various outlier recognition techniques

Outlier recognition techniques	Accuracy per-day dataset	Accuracy per-month dataset
SVM	97.37	97.65
DBSCAN	99.05	99.25
IF	98.77	99.01

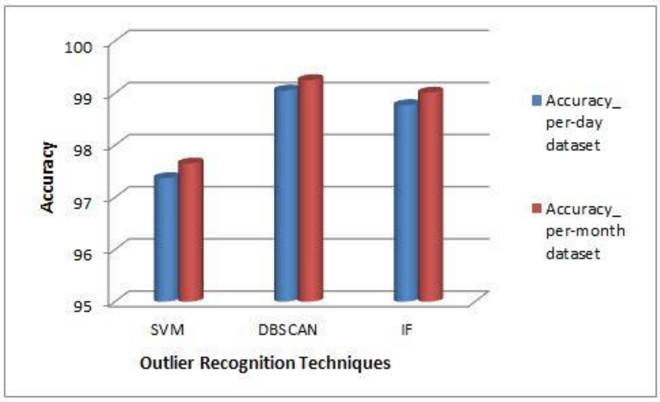

Figure 11. Comparison of accuracy of various outlier recognition techniques

Accuracy of the three techniques used for outlier recognition is evaluated using per-day and per-month datasets, and is shown in Figure 11.

It is evident from the figure that DBSCAN technique recognizes the outliers more accurately when compared to SVM and IF.

6. CONCLUSIONS

In agricultural countries, a smart agricultural field monitoring system might be quite useful. This approach can aid in the accurate management of agricultural land. This technique keeps water from being wasted. As part of this paper's future study, more sensors with more data analysis could be developed. The proposed architecture compares three outlier recognition techniques and from the analysis it is evident that DBSCAN technique recognizes the outliers more accurately when compared to SVM and IF. As the data from sensors are subjected to outlier recognition and filtering, the total amount of data sent to the cloud is reduced. This in turn balances the computational load by distributing the business logic between several layers. As a result, significant cloud resources are saved. The proposed architecture also reduces waiting time by processing the real time data locally near the field without sending the data to the cloud and also uses actuators which sends notification based on the analysis.

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