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MICROCLIMATE PRECISION FARMING ROBOT (MOVING BOT) AN EDGE-AI MICROCLIMATE PRECISION FARMING ROBOT FOR SMART CROP MONITORING AND ADAPTIVE RESOURCE MANAGEMENT

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ABSTRACT

This paper introduces a Microclimate Precision Farming Robot that is designed to make farming smarter and more efficient. Traditional farming often depends on weather forecasts and manual checks. These methods might not show the conditions in different parts of a field. Because of this farmers might use much water or other resources, which can damage crops and reduce yields.To solve this problem the robot uses IoT-based sensors to keep an eye on soil and environmental factors in time. It follows a two-part plan. One part collects data from the field. The other part uses Edge-AI to determine when and how much to water and to check the health of the crops. Since all the processing takes place on the robot it does not require a connection to the cloud. This makes the system more dependable and quicker.The aim is to cut down on water waste improve crop health save energy and help farming. It also supports the vision of Atmanirbhar Bharat by providing a solution, for farmers.

KEYWORDS: Microclimate Monitoring; Precision Agriculture; Edge AI; TinyML; IoT-Based Smart Farming; Autonomous Farming Robot; Intelligent Irrigation; Environmental Sensing.

INTRODUCTION

A. Operational Context and Environmental Challenges

We see the healthy crop growth tends to be affected by temperature humidity soil moisture

and sunlight.Normal farming is generally based on weather.The complication is that the conditions vary from one side of a field to another.There could be soil in some areas and enough moisture in others.These small variations can go unnoticed with the result of waste water, inconsistent crop growth and lower yields.So we require an automation system that is able to constantly keep an eye on field conditions and react to them based on what crop needs.

B.Limitations of Conventional Farming Approaches

We notice that conventional irrigation practice tends to be scheduled or decision-based.While traditional irrigation techniques are successful in some applications, they cannot always respond to the variations of local weather or the changes in soil water content.Sensor-focused systems have their drawbacks, mainly when it comes to transmitting data to the cloud.It is possible to take longer for the information to be sent to the cloud.Internet connection for sensor-based systems, internet connection is also necessary.Internet connectivity might be an issue in farming regions.That means prompt decisions about irrigation and crop condition may not always be made.

C. Technical Core Contributions of Microclimate Precision Farming Robot

In order to solve the above problems, I have been developing the Microclimate Precision Farming Robot. The Microclimate Precision Farming Robot is the combination of the sensing technology and Edge-AI. The Microclimate Precision Farming Robot produces a visual map of the various parts of the field.The Microclimate Precision Farming Robot can still make decisions even when it's not connected to the cloud.The Microclimate Precision Farming Robot has a dual path design.On one route the Microclimate Precision Farming Robot is gathering real time data (soil moisture, temperature, humidity and all the other relevant environmental parameters).The Microclimate Precision Farming Robot uses Edge-AI to run the analyses that determine when to irrigate and when to check crop health. The two paths combined. It allows the Microclimate Precision Farming Robot to react to the changes in the field. Also, the cost and the energy-efficient are important. When the Microclimate Precision Farming Robot processes the data on board.It limits the communication. Makes it more practical for daily use of farming.

D. Conventional. Irrigation Approaches

In previous farming systems. Mostly relies on the observation of soil, the fixed schedule of the irrigation, and the general data of the weather. This approach is simple. However, it is not

always accurate in the overview of the soil conditions over the whole field. Sometimes, the over-long irrigation is continued.

Even though some area is already wet or the dry spots are not detected until the stress shown up in the plants. Fortunately, there is some help with the sensor-based monitoring. But many of them only. Not made the local decision. There is a gap between the monitoring and the control of the field. We need a solution to adapt the situation. Not think everything is same. As last time.

E. Edge-AI as solution for efficient processing

New horizons arise with the usage of AI and IoT in precision agriculture. One can use environment sensors in the field to continuously record field data. Use AI models for analysis of these readings and detect changes and improve the irrigation decision. But the integration of complex AI models into low power agriculture bots is not always simple. Low computing power, energy consumption, network dependency can affect the overall performance.

We would like to present a Microclimate Precision Farming Robot powered by Edges-AI. Instead of transmitting the data to the cloud always, the robot processes the data on the device itself. Thus, the communication latency is significantly decreased, leading to fast and accurate decisions. Besides that, the robot will track microclimate changes from day to day and respond to the needs of various zones within the farm. We aim generally to make water usage efficient, enhance crop productivity, achieve sustainability and reduce the costs.

MATERIALS AND METHODS

A. Dual-Path Environmental monitoring and Control

Microclimate Precision Farming Robot (MPFR) is based on a dual path architecture for its own self-regulation of agricultural work and for its continuous environmental monitoring. The first path is data collecting from various sensors, such as those monitoring temperature, humidity soil moisture,light.

If the measurements go outside of the preset ranges the controller will take the appropriate corrective action after having monitored the parameters.

Machine learning algorithms are part of the second route through the system and they improve the efficiency of sensor data interpretation.With this feature the system can anticipate micro-climatic changes and hence make a smart decision on farming.It also makes the monitoring system more efficient and opens up the prospect of automatically controlling

the irrigation and the crop environment.

B. Microclimatic DataAcquisition and Feature Extraction

As for the state of the farm at the present time, the robot is making regular measurements to establish the environmental conditions.These are expressed as:

X(t)=[T(t),H(t),S(t),L(t),R(t)]

with T being temperature, H humidity, S soil moisture, L light intensity and R rainfall.
As a way to lower the fluctuations in measurements, we perform an operation to filter and normalize the data first.The statistical summary features we extract such as mean and min, max for the dataset are important to spot possible changes of the environment.
Below is the formula using for normalization.

X_norm = (X X_min) / (X_maxX_min)

At last the features will go to another stage a prediction model.

C.Smart microclimate forecast as well as decision aspect

By combining historical along with real-time data of weather parameters through the LSTM machine learning model, we can get the result. The fact that the model is very capable of catching the time-series pattern lets it foresee alterations of temperature, humidity, and soil moisture level as well.With these forecast the robot can come up with the plan of action. The irrigation control mechanism is represented as:

I(t)=
begin{cases}
1,&S(t)<S_{min}
0,&S(t)\geq S_{min}
end{cases}

In which S(t)'s the soil moisture measured and S_{min} is the minimum moisture threshold.
If soil moisture is not enough the irrigation pump is turned on. There is also a change in temperature and humidity which is watched in order to find conditions for crop growth. This is a way to manage things that will use less water without hurting crop management.

D.Model Optimization and Embedded Hardware Deployment.

The machine learning model is first trained using floating point precision. Then improved using INT8 quantization, which saves memory and computing power.

The quantization process is shown as follows:

q=operatorname{round}left(frac{x}{s}right)+z

The value x is the value the value s is the scaling factor the value z is the zero-point and the value q is the quantized value.

A system for embedded deployment is needed to place the model in the robots microcontroller.

The controller gets infomer from sensors, which help it marketical decisions regarding irrigation pumps motors and other actuators. System constantly evaluates the surrounding conditions of the plant. it generates control signals according to the crop field conditions. This results in lesser human intervention and a steady microclimate control through the intelligent use of resources

RESULTS AND DISCUSSION

A. Dataset Generation and Sensor Data Collection

To assess the performance of the Microclimate Precision Farming Robot we built a system to monitor a range of environmental conditions in the field. The robot takes real time readings via a range of sensors (temperature, humidity, soil moisture and LDR). The ESP32-CAM takes images of the plants to look for any visible signs of stress or disease. A number of test conditions were used to test the system (dry soil, high temperature, low humidity, changing light levels etc). The sensor data is processed on the ESP32 microcontroller to determine the state of each plant and act accordingly.

Fig. 1: **Microclimate Precision Farming Robot development and working pipeline.**

B. Quantitative Performance and Sensor Analysis

The robot's performance is assessed on the basis of sensor readings, plant monitoring and the robot's own response. It will of course be helping to maintain the right growing conditions through the monitoring of the environment and the appropriate action being taken.

TABLE 1: SENSOR PERFORMANCE AND SYSTEM ANALYSIS.

Parameter	Sensor / Module	Expected Function
Temperature	DHT11 / DHT22	Measures temperature
Humidity	DHT11 / DHT22	Measures air humidity
Soil moisture	Soil moisture sensor	Detects soil water level
Light intensity	LDR sensor	Measures sunlight intensity
Plant monitoring	ESP32-CAM	Captures plant images
Controller	ESP32	Processes sensor data
Water management	Water pump	Provides water when soil is dry
Cooling	Mini mist sprayer	Reduces heat around plants

C. System Efficiency, Response Time, and Power Consumption

Firstly, we have the Temperature & Humidity Sensor that will provide us with the surrounding environment's parameters. Next up comes the Soil Moisture Sensor that ensures the right water level of our soil. Lastly, there are the Light Intensity Sensors (LDR), which will measure how much light our crops get . All this data gets processed through the ESP 32 Microcontroller, ensuring that everything runs smoothly without anyone having to intervene manually! The result? We'll end up getting automatic watering whenever necessary or cooling down via mist sprayers if things start heating up too much – all done seamlessly thanks to this brilliant little contraption!

To top off matters nicely then imagine seeing pictures captured continuously by an ESP32CAM attached directly onto such bots – giving you visuals into subtle alterations happening overtime amongst leaves themselves whether normalcy reigns supreme yet. early detection being key element especially where diseases are concerned so letting everyone know instantly what needs doing next time round! Finally wrapping things up neatly tying them together using some sort of IoT Platform whereby people interested may check live updates regarding specific crop statuses easily accessible anywhere anytime convenience first folks.

CONCLUSION

Microclimate Precision Farming Robot is an automatic controller of agricultural processes. The aim of this project is to regularly assess the state of the environment and make adjustments so that the plant can be given proper care.

Data from various sensors regarding different parameters (temperature, humidity, soil moisture, and light) are sent to ESP32 which processes the data to estimate the health of the plant. On the basis of the data obtained, ESP32 will either activate the water pump or mist sprayer.

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