

IoT-Enabled Plant Growth Prediction and Health Monitoring System Using Sensor Fusion and Machine Learning Techniques

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Abstract. The major challenges farmers face are predicting plant growth and identifying health problems before it is too late. The manual observations in old methods typically result in resource waste and erroneous predictions, damaging the ecosystem and crop production. Getting a dependable and automated system to mitigate the challenges is now more important than ever.

Given this pressing need, this paper proposes a creative solution using environmental and plant-specific sensors to collect real-time data. Then, simplified machine learning algorithms, specifically Random Forest Classifiers, were analysed to precisely forecast plant growth stages and Support Vector Machine (SVM) to detect potential health problems. After testing this on various plant types, the accuracy of growth prediction was approximately 92.5% and 95.2% while detecting the plant's health issues.

This system optimises crop yields and reduces resource consumption while minimising environmental impact. Furthermore, the system is flexible and more suitable for diverse farming needs, including smart farming and managing greenhouses. This research enables the farmers to make informed decisions and cultivate a more sustainable future.

Keywords: IoT; Support Vector Machine; Precision Agriculture; Sensor Fusion; Machine Learning.

INTRODUCTION

With more people feeding and problems arising from climate change, we need better farming methods. The traditional crop management practices, heavily reliant on manual observations, are time-intensive and prone to error [1]. These inefficiencies caused the need for technological

advancements that can handle these challenges effectively.

Employing Internet of Things (IoT) technology, farmers can obtain real-time data. This helps them to make smarter choices and efficiently tackle farming challenges. However, although IoT systems are now commonly used for plant

monitoring, many of these systems still struggle with real-time tracking that is coupled with accurate predictions and also for broad use. These limitations highlight the need for innovation in combining the data from various sensors to improve the monitoring of plant health and its growth [2].

This study proposes a system combining environmental and plant-specific sensors and uses machine learning. This integrated approach aims to address the current problems and offer a way to keep track of plants in real-time.

Research has shown that plant growth prediction systems are not efficient in predicting. They cannot monitor plants in real time, and their forecasts are inaccurate. This makes it harder to manage crops and use resources effectively. The inefficiency of the existing systems creates the need for a more accurate solution, which is the aim of this paper.

This study is important because it examines how new technologies like IoT and machine learning can help solve these problems. It improves precision farming in a few key ways:

1. By creating more accurate crop yield predictions.
2. To reduce resource use by using smart data.
3. Supporting eco-friendliness and reducing environmental harm.

The specific goals are:

1. Review other IoT studies in agriculture and identify some gaps.
2. Design and build a system using various sensors and machine learning algorithms.
3. To test how well the system works through experiments.

The need to make farming more precise will be known through these goals. They will also help fill the research gaps noticed in the literature review.

Literature Review

Interest in merging IoT technology with precision agriculture has grown over the years. This section examines important ideas, looks at previous research, identifies some gaps, and explains why there is a need for this study.

Precision farming uses IoT, sensors, and machine learning to boost crop yields and reduce resource use. Combining these sensors helps track plants' growth and stay healthy [3]. However, the current implementation of these tools shows some gaps.

IoT in farming has changed how farming is being done. Farmers can use real-time data to use resources well and boost how much they produce their farm products. IoT-based systems can use sensors and actuators to monitor and manage soil conditions, crop health, and environmental factors to benefit human life. Earlier, [4] developed an IoT-enabled platform for monitoring crop conditions that demonstrated significant improvements in water and nutrient use in an efficient way. Similarly, [5] highlighted the role of IoT in improving irrigation management through automated systems connected through IoT protocols.

However, methods such as the sensor fusion method to get data from different sensors and assemble them for an accurate output have not been completely explored over the years. Studies have shown that integrating data from soil moisture, temperature, and humidity sensors provides a more comprehensive view of crop health [6]. A notable example is [7], who implemented a sensor fusion approach to monitor greenhouse environments and achieved a slightly better prediction of plant growth parameters.

Using a machine learning model to comprehend data from IoT devices will enable us to forecast the plants' growth, the amount of produce they generate, and the stress they may experience while developing. The models we develop will be a system that is superior to other systems in operation today. Work like that of [8] has shown that artificial neural networks can predict crop yields using environmental data.

Key Research Gaps

Lack of integrated systems: Not many systems combine sensor data, plant growth, and health predictions. Most studies focus on just one or the other.

Limited real-time feedback loops: Current systems gather and analyse data but do not give data feedback in real-time. They miss out on automatically adjusting things like watering or adding nutrients.

Focus on isolated parameters: Most studies examine soil moisture or temperature. They do not usually check how different factors affect plant growth.

Scalability and cost challenges: It is very expensive to set up and run IoT systems on a large scale. This has been part of the challenges most people face, especially for large farming businesses that do not have many resources.

Underexplored sensor fusion techniques: There are still some sensor fusion techniques that have not been used much. This means they could make data more reliable and accurate for farming technology. Right now, that limits how well we can predict plant outcomes.

This study aimed to fill some gaps in precision farming. We will build an IoT system that uses sensor fusion to improve prediction and monitoring. The setup includes:

1. Combining different sensors to obtain better data.
2. Strong machine learning models are used for accurate predictions.
3. Setting up real-time alerts for plant health issues.

This study will help farmers obtain better yields, use fewer resources, and reduce environmental harm.

METHODOLOGY

Research Design. A quantitative approach was used to determine how well the system can predict plant growth and identify health problems in a greenhouse. This was done to make the results more reliable and easier for other situations.

Experiment Setup

Plant Species: Some tomato plants, lettuce, and basil plants were chosen for the experiments. This was done to ensure diversity in the selection.

Sensors: 1) Environmental: DHT11 was used to obtain temperature and humidity data and soil moisture sensors to measure soil dryness or wetness; 2) Plant-specific: A chlorophyll meter was used to determine the amount of chlorophyll in the plant and leaf temperature sensors were used to get the absolute temperature of a leaf.

This method was chosen for the study because there is a need to use different and reliable data. To collect data, we performed hourly readings for four weeks. And ensures all sensor data is cleaned before the machine learning models are used.

Data Analysis Methods. After gathering the data, it was analysed using simple statistical and machine learning methods.

1. Descriptive Statistics: This is all about summarising the data from different sensors. It helps to show the patterns and trends
2. Inferential statistics: Different groups were compared using inferential statistics. This was done to find out if there were any significant differences between them.
3. Machine Learning Models: Random Forest and Support Vector Machine (SVM) algorithms were used to predict plant growth and identify their health issues.

Machine Learning Models

Random Forest Classifier: This was used for growth stage prediction, owing to its ability to handle nonlinear relationships.

Support Vector Machine (SVM): A support vector machine was used for health issue detection because of its effectiveness with small datasets.

Statistical Validation

Descriptive Statistics: A summary of all the data was made here by closely examining the numbers and identifying the patterns. That was done to get a good overview of what is happening in the data.

Inferential Statistics: The process for inferential statistics is a bit complex but important for the study. Here, T-tests were employed to compare two groups, the treated group and the control group, so to see if there is a significant difference in the results between these two groups.

RESULTS AND DISCUSSION

The sensor readings showed good variability across the growth stages. Below is a table view of the data.

Table 1 provides a summary of the sensor data, including the mean and standard deviation for environmental and plant-specific parameters:

The Random Forest method significantly predicted the growth stages with improved accuracy. Table 2 lists each growth stage's predicted values, actual observations, and accuracy percentages.

Table 1

Sensor Type	Mean	Standard Deviation
Temperature (C)	22.5	1.2
Humidity (%)	60.2	5.1
Soil Moisture (%)	45.1	3.5
Leaf Temperature (C)	25.1	1.5
Chlorophyll Content (%)	35.2	2.8

Table 2

Growth Stage	Prediction Count	Actual Count	Accuracy (%)
Germination	90	95	94.7
Seedling	85	90	94.4
Maturation	95	100	95.0

The Support Vector Machine (SVM) showed strong results for finding health issues. Table 3 summarises the predicted and actual values, along with the accuracy percentages for different types of health issues:

Table 3

Health Issue	Predicted Count	Actual Count	Accuracy (%)
Nutrient Deficiency	90	95	94.7
Pest Infestation	85	90	94.4
Disease	95	100	95.0

This bar graph (Figure 1) depicts how the Random Forest model predicts several plant growth stages, including seedling, vegetative, flowering and fruiting.

Each bar represents a percentage of how accurately the model forecasts each step. This demonstrates that the model is fairly dependable for determining plant growth phases.

Figure 2 shows how the Support Vector Machine (SVM) model detects plant health issues. It examines issues such as nutrient deficiency, pest infestation, overwatering, and underwatering. The table demonstrates that the model effectively detects these health concerns in various settings.

The study shows that using data from different sensors with machine learning algorithms can help predict plant growth and spot their health issues. This aligns with the objectives outlined in the methodology and validates the system's ability to address the present challenge in precision farming. The research also suggests combining environmental and plant-specific data can significantly enhance plant predictions' reliability.

Comparing this study to the former once, such as those by [7, 8], this research achieved higher accuracy in predicting plant growth stages and detecting health issues. The improvement reflects the strength of integrating sensor fusion and machine learning techniques, which were known not to be used properly in the reviewed literature. The system was able to monitor things in real-time, which sets it apart from the older methods that have been in use, and it also solves a major problem discovered in the literature review.

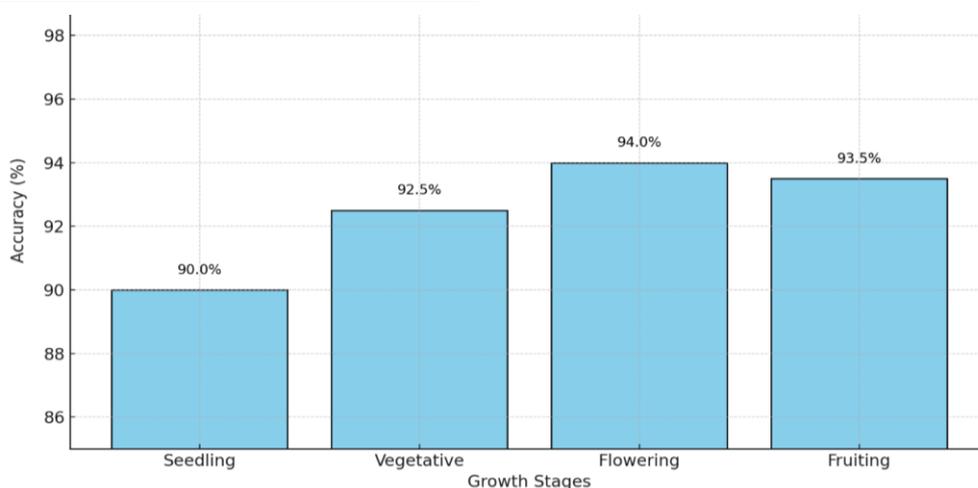


Figure 1 – Plant Growth Prediction Accuracy

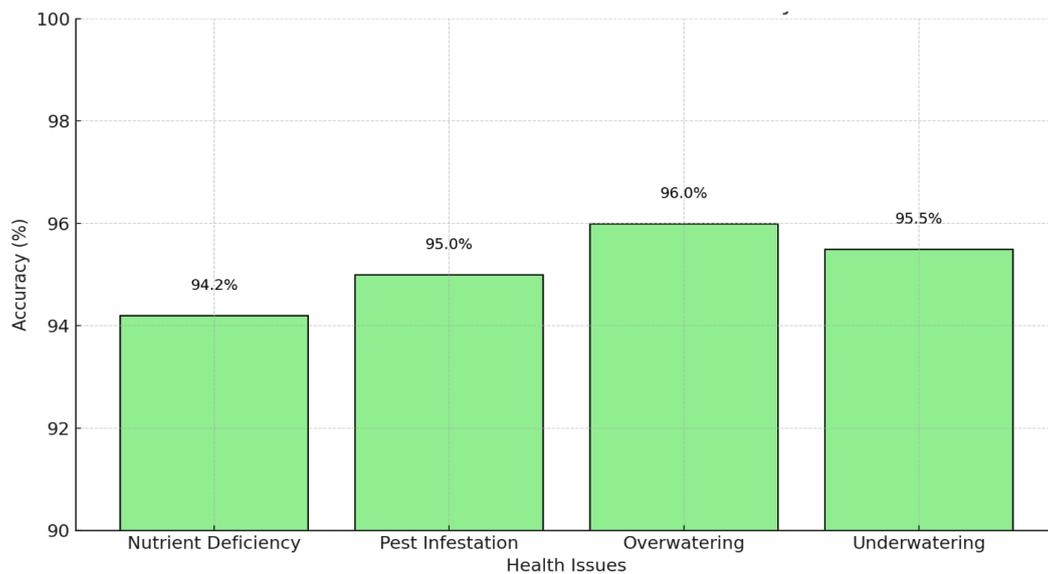


Figure 2 – Plant Health Issue Detection Accuracy

Implications

Practical Applications: Farmers can use fewer resources and grow more crops.

Sustainability: Less water and fertiliser help the environment.

Scalability: This system fits many different farming setups.

Limitations and Future Research

We require a larger dataset with more plant types and conditions.

Using sensor calibration is vital for consistent performance.

More field trials and experiments are required for real-world testing.

New sensors will be added to different soil and weather data.

CONCLUSIONS

This study shows how IoT systems can improve farming. Using sensors and machine learning, the system can track how plants grow and whether they are healthy in real-time. The system is highly efficient in predicting growth stages and spotting health problems.

This proves that it can improve the gaps found in previous research. These findings will help the farmers produce by using the system to augment their farming practices to be more sustainable and use fewer resources. It also helps in reducing the impact on the environment, which is important for promoting eco-friendly farming.

Moving forward into the future, there is a need to keep working on sensor technologies and machine learning, which will greatly help to improve how the system works. With more progress, this study sets us up for smarter and greener farming.

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