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Intelligent Orchard monitoring: IoT integrated Fuzzy Logic based real-time apple disease prediction encompassing environmental factors

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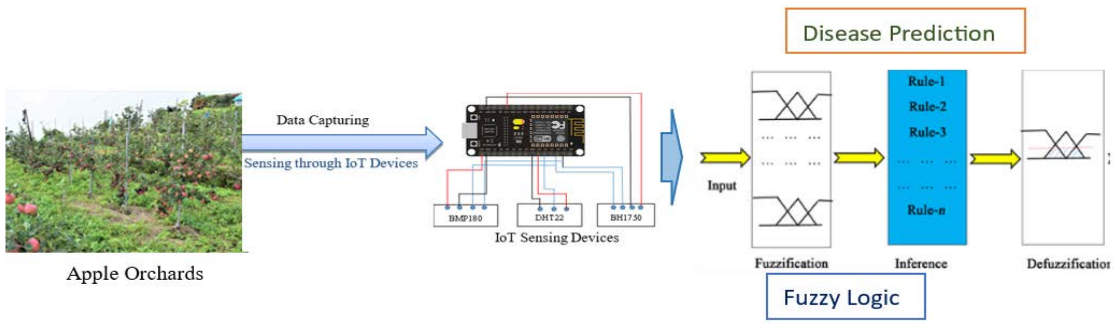
Article

ABSTRACT



This work presents a novel methodology for apple disease detection based on environmental factors, integrating the capabilities of the Internet of Things (IoT). Advanced sensors are placed in apple orchards to continuously monitor various environmental factors such as temperature, humidity, pressure, and light. The data gathered from these sensors is analyzed using the Mamdani fuzzy inference system (MFIS) to predict possible apple diseases. The use of advanced sensors, cloud storage, and the Mamdani fuzzy inference system proved effective in timely disease detection along with inclusion of environmental factors. According to predicted outcomes, a recommendation system is also presented in the mobile application. Initial experiments in Shimla, India, showed that this system is effective and efficient, with minimal delays in different stages. The study also compares this new approach with current advanced methods in disease detection.

Keywords: Internet of Things (IoT), Apple Disease Detection, Environmental Factors, Fuzzy Logic, Real-time Monitoring.

INTRODUCTION

India, with its diverse climate, produces a vast range of fruits and vegetables, ranking second globally in production.[1] In 2017-18, India produced about 97.055 million tonnes of fruit and 179.692 million tonnes of vegetables, enabling exports worth 1459.93 USD million, including 655.90 USD million from fruits and 804.03 USD million from vegetables.[2-5] Deciduous fruits, like apples and pears, are a significant variety produced, especially in regions like Jammu and Kashmir, Himachal Pradesh, and Nagaland. Apples stand out in importance, with India being the world's sixth-largest producer, accounting for 2.371 million tonnes in 2017-18.[6] Jammu and Kashmir leads in apple production, followed by Himachal Pradesh and Uttarakhand, presented in Figure 1. Apple farming provides livelihoods to over three million people.[7,8] However, apple crops often face diseases like Scab and Powdery Mildew, leading to an average annual loss of 11.34%. Traditional methods are insufficient to tackle these challenges, and the difficult terrains make regular surveillance hard.[9,10] With India's growing population, there's an urgent need for affordable technological solutions to ensure food security and minimize crop losses.[10-12]

India cultivates several commercial apple varieties, including Benoni, Irish Peach, Coxs Orange Pippin, Ambri, White dotted Red, American Apirouge, Red Delicious, and Golden Delicious. While pest and disease-resistant apple varieties have been introduced, significant losses from diseases and pests persist. Apple crops, like other crops, are susceptible to numerous pre-harvest and post-harvest diseases and pests.[13] Weather plays a crucial role in the onset, progression, and severity of apple diseases, leading many to be termed “weather diseases” Apple crops in India are affected by a range of diseases:[14-16]

- Fungal: Diseases include apple scab, powdery mildew, and blue mold.
- Bacterial: Notably, fire blight and gall formation.
- Viroid: Apple scar skin is prominent.

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- Viral: Ailments such as apple mosaic and stem grooving are prevalent.

Fungal and bacterial diseases have significantly impacted apple crops, causing 30-40% damage in the past three years. Diseases like scabs, Alternaria Leaf Blotch, and Powdery Mildew have been particularly harmful.[6] In 2013, an outbreak of Alternaria disease wreaked havoc in Jammu and Kashmir. From 2014-2022, as depicted in Fig 1, apple production saw fluctuations, with 2022 recording over two million metric tons, marking an increase from the previous year.[17] Jammu and Kashmir predominantly contributed to India's apple yield in that period.

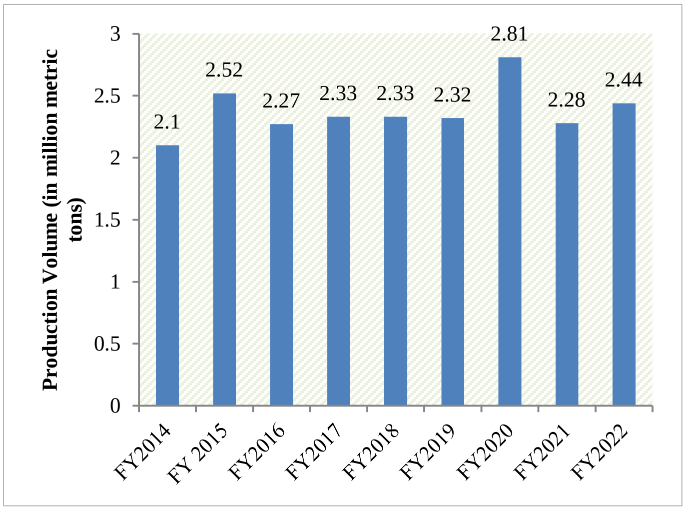

Figure 1. Production volume of apples India FY 2014-2022

Environmental Factors Affecting Apple Disease

Apple cultivation demands over 1000 hours of cold weather, with temperatures below 5°C; deviations impact yields. Additionally, apple production hinges on precise irrigation and environmental factors. Over-irrigation or under-irrigation can negatively affect yields, and there's a direct correlation between temperature patterns and irrigation needs. An IoT-based environmental study can pinpoint disease causes and ideal conditions for maximum production. Many studies have explored sensor network-based systems to optimize yields. Using IoT is advantageous as it eliminates the need for fixed infrastructure, and the same sensor setup can be utilized across multiple orchards.

Effect of temperature on disease development: Temperature plays a pivotal role in the onset and progression of diseases in apple crops. Fungal diseases tend to manifest at cooler temperatures, while bacterial diseases exacerbate at higher temperatures compared to fungal infections.[18] The pigmentation in most plants is regulated by the relative concentrations of carotenoids, chlorophyll, and anthocyanins, which are crucial markers for food health. In hotter climates, fruit anthocyanin levels decrease. Fluctuating temperatures between 10-30°C during apple fruit development stages can lead to the emergence of various diseases.[19] Table 1 illustrates the diseases of apples which may be caused by temperature variation.

Table 1. Apple Disease Due to Temperature

Disease name	Appearance part	Reason for appearance
Apple scab	Fruit, flower, leaf	Average Temperature 20º C.
Marssonina leaf blotch	Leaf	High rainfall, temperature ranging from 20-22º C.
Black Rot Canker	Fruit and leaf	20-24º C temperature and moisture
Powdery Mildew	Fruit and leaf	Temperature lies between 10-25º C
Sooty blotch/ Fly Speck	Fruit	Temperature 18-27º C.
Alternaria leaf spot / Blight	Leaf	Temperature 25-30º C
Seedling blight	Root	Low temperature below 24º C.

Effect of relative humidity on disease development: By varying infection processes, humidity triggers disease progress. Rain and high humidity initiate diseases in different parts of the apple plant including fruit. The fiber density of the apple decreased more slowly at high relative humidity and the apple lost weight at low relative humidity. Atmospheric humidity >70% is favorable for disease development and infection in apple plants. Powdery mildew, Core rot, brown rot seedling blight, etc. are some common diseases of apples in Himachal Pradesh that are caused by high relative humidity.[20] Table 2 illustrates the diseases of apples which may be caused by temperature variation.

Table 2. Apple Disease Due to Humidity

Disease name	Appearance part	Reason for appearance
Collar Rot	Root	Over-watering, moisture.
Powdery Mildew	Fruit and leaf	Humidity is greater than 70%
Core Rot	Fruit	Warm weather and high Humidity
Brown Rot	Fruit	Humid wet conditions
Seedling blight	Root	High humidity.

Effect of location and height on disease development: In the early 1980s apples were known to be cultivated at 12001500 meters altitude. In the 2000s, the apple orchards shifted to 1500-2500 meters because of the warming of the surface temperature in the last 3 decades. Apple orchards have consistently shifted upward with the rise in surface temperature. Presently in the state, apples are now being cultivated at more than 3500-meter elevation. The increase in global warming has led to diseases appearance like apple scabs, Alternaria, fly speck, Marssonina leaf blotch, etc. When the climatic conditions favor the optimum scenario then these diseases sometimes become endemic.[21]

RELATED WORK

Rana et al.[22] explored the effects of climate change on apple cultivation in Himachal Pradesh. Due to increasing temperature trends and decreasing precipitation, apple cultivation has shifted to higher altitudes. Specifically, temperatures in the apple-growing regions of Kullu and Shimla have risen between 1.8 to 4.1°C over the past two decades, causing a decrease in chill units (CU) hours. Moreover, reduced snowfall during early and late winters indicates shorter winter periods. Samajpati et al.[23] conducted a review of methodologies used for apple fruit disease detection through image processing. The study summarized various techniques related to color, texture, segmentation, and classification, along with their pros and cons. Sahu et al.[24] investigated the shift in apple orchards in Himachal Pradesh due to changing climatic conditions. Optimal apple-growing conditions have moved upwards in altitude, from 1200–1500 meters in the 1980s to 1500–2500 meters in the 2000s. Factors like chilling hours, annual rainfall, and mean surface temperature during apple-growing seasons have been impacted by global warming. While lower altitudes are seeing reduced apple production, higher altitudes are becoming more favorable for apple cultivation, bringing about socioeconomic changes for the local farmers. Kumar et al.[25] studied the effect of abiotic factors on in vitro conidial production, germination, and infection in detached apple leaves by Marssonina coronaria, the causative agent of Marssonina blotch. Conidia germination is optimal at 20°C and high humidity levels. A temperature of 20°C with 48 hours of leaf wetness was found to be the most favorable for the development of Marssonina blotch, with a minimum of 6 hours of leaf wetness needed for infection. Sheel et al.[26] proposed a system based on the Internet of Things (IoT) to predict diseases and their impacts on apples under different weather conditions. IoT boards with sensors and Wi-Fi transceivers will be used to gather data, which can then be analyzed for disease prediction and recommendations. Feng et al.[27] introduced an apple orchard intelligent monitoring system based on IoT. This system includes modules for dynamic monitoring, farming suggestions, planting decision-making, and information dissemination. It offers detailed apple growth monitoring data and farming decision-making support. The research aims to advance the adoption of IoT technology in agricultural production. Ahmadi et al.[28] highlighted the impact of rising air temperatures due to climate change on deciduous trees in cold regions of Iran. This increase in temperature will limit areas suitable for apple cultivation. By the 2090s, the minimum and maximum temperatures during apple growth might rise to 16.7 and 33.4°C, respectively, under a pessimistic scenario. These changes surpass the vulnerability threshold for apple trees, emphasizing the effects of climate change on fruit trees. Pramanick et al.[29] developed a reckoner for the apple-growing Shimla region in Himachal Pradesh. They found that lower chill units (300 hr) resulted in a 50-day bud break period, while higher chill units (1500 hr) shortened it to 13 days. The declining productivity of apples in the region over the past two decades is attributed to various factors, including the expansion to marginal areas, monoculture of certain apple varieties, and inconsistent climatic conditions. A more extended study is recommended to understand the effects of global warming in Shimla. Sharma et al.[30] analyzed apple flowering phenology and weather data from 2004-2013. The apple flowering date varied from March 16 to March 29, but no significant trend was found when correlated with temperature variations. The diversity of pollinators remained consistent, and advancements in apple flowering had no notable impact on insect pollinator populations. The presence of honey bee colonies (Apis mellifera) was found to positively influence fruit sets in apple orchards. Apple trees near bee colonies showed a higher fruit set compared to trees further away. Eisavi et al.[31] utilized the Enhanced Vegetation Index (EVI) from MODIS sensor images (2003-2014) to analyze AOP events. Random forest regression (RFR) assessed the connection between temperature changes/Lake Desiccation and AOP. Results showed EVI's efficacy in estimating AOP, with a trend towards earlier season starts in the region. Argenta et al.[32] investigated the influence of environmental conditions on apple quality in Brazil. Temperature, chilling hours, and the number of days from bloom to harvest varied across sites. 'Gala' apples were stored in a controlled atmosphere, while 'Fuji' apples had varying storage conditions based on harvest time. Dong et al.[33] studied sclerotium germination and hyphal growth of S. rolfsii based on environmental factors. The optimal temperature was 31.5°C, and soil water content had to exceed 30%. Germination was high in sawdust but inhibited in nursery substrate. Sun et al.[34] introduced a high-efficiency rainwater irrigation (HRI) mode for dryland apple orchards, combining rainwater harvesting with a solar-intelligent irrigation system. This mode improved soil drought and significantly increased apple yield and water-use efficiency. Juhnevica-Radenkova et al.[35] analyzed the effects of O3 treatment on various apple cultivars. Ozone treatment influenced the epicuticular wax structure and accelerated the natural aging of waxes on apples. The impact varied across cultivars, with some benefiting from ozone exposure and others experiencing accelerated damage. Bosco et al.[36] examined the microclimate and production of apples grown under hail nets. Hail nets reduced photosynthetically active radiation (PAR) and wind speed without affecting temperature, humidity, or rainfall. Apple yield was generally higher under hail nets, especially after hailstorm events. Bertolino et al.[37] studied the relationship between environmental/agronomic variables and vole population densities. Vole abundance was influenced by neighboring field vole populations, adjacent kiwifruit orchards, the irrigation system, apple-tree age, and tilling practices. Flood irrigation and regular soil tillage could reduce vole populations.

Table 3. Research Contribution to Apple Disease Detection

Authors	Factors considered	Effect of factors on apple production
Rana et al. [22]	Altitude	Apple farming is shifting to higher regions in Lahaul, Spitti, and Kinnaur.
Sahu et al. [24]	Altitude	Apple yield improves with increasing elevation.
	temperature, relative humidity and duration of leaf wetness period	Conidia thrive across temperatures from 5-30°C, especially at 20°C. They also flourish at all tested humidity levels, with peak germination at near-complete humidity (>90%).
Sheel et al. [26]	different whether conditions.	Variations in climate significantly influence apple growth and quality.
Ahmadi et al. [28]	Temperature	Rising temperatures could jeopardize deciduous trees in Iran's colder areas.
Pramanick et al. [29]	global warming	Apple yield is on the decline.
Sharma et al. [30]	apple flowering phenology and weather parameters	Minor weather changes haven't impacted apple flowering or pollinator variety.
Eisavi et al. [31]	temperature	Temperature fluctuations have notably altered AOP.

	changes/Lake Desiccation and AOP.	
Argenta et al. [32]	growing site environmental conditions	'Fuji' apples from the chilliest location exhibited the most length-to-diameter ratio and water core index at picking time and later exhibited more CO2 damage and flesh browning.
Dong et al. [33]	Effects of Environmental Conditions on Sclerotium Germination and Hyphal Growth of the Pathogen	S. rolfsii's sclerotium germination and hyphal growth are optimal at 31.5°C, requiring soil moisture above 30%.
Juhnevica-Radenkova et al. [35]	Effect of O_3 treatment on the quality of different cultivars of apples	Ozone treatment can help retain the sensory and nutritional quality of apples during six-month storage, but its efficacy varies based on apple type and ozone concentration.

METHODOLOGY

In this paper, we have presented a methodology for apple disease detection depending on environmental factors. The methodology focuses on identifying the factors that cause apple disease while integrating Internet-of-things (IoT) applications in orchards. By utilizing cutting-edge sensors and actuators, it is intended to transform orchards into intelligent orchards. This study used orchard monitoring data, including temperature, humidity, pressure, and light. The first section of the system design architecture consists of data transmission to a cloud server and automated monitoring for additional analysis. As part of the project plan, a hardware package for identifying the factors that cause apple disease will be made using microcontrollers and sensors. The microcontroller is connected to the sensing sensors to create a network of functionally ready devices. The software applications gateway will then be connected to the microcontroller, allowing it to receive and process data from the sensory devices. The paper presented the Internet of Things (IoT) and artificial intelligence together for predicting disease. Here IoT devices are used for sensing environmental factors such as temperature, light, altitude, and humidity from Apple Orchard. The data captured is processed on the Arduino UNO unit. The WiFi module is used to send data to a cloud storage server and fuzzy logic is implemented to identify the type of disease. Fig 2 represents the flowchart of the entire work that is being presented in this paper. The entire work is divided into four basic steps: data capturing, data transmission, disease prediction, and recommendation. All these steps are discussed in the below sub-sections.

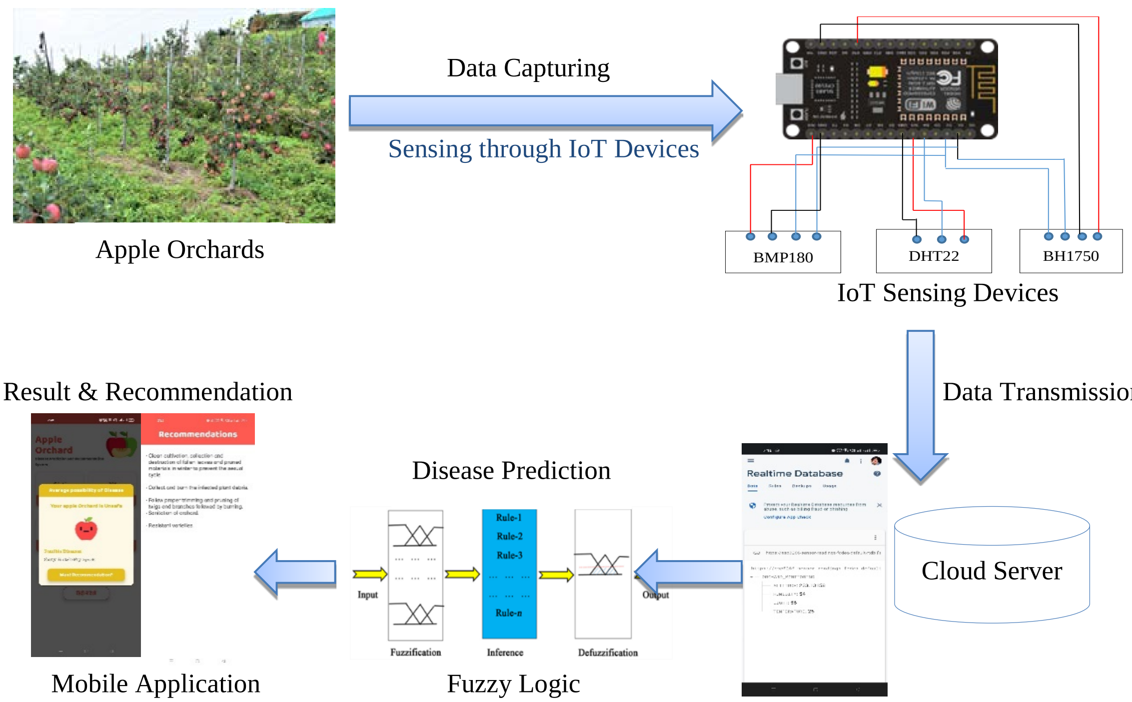

Figure 2. Working Procedure for Apple Disease Detection

4.1 Data Capturing

Using IoT sensors, environmental factors are gathered in this step. Four sensors have been set up to detect the environmental factors that can cause disease in orchards. For this, four different types of sensors, including the temperature and humidity sensor (DHT22), the altitude sensor (BMP180), and the light sensor, are utilized (BH1750). NodeMCU (ESP8266) is used to design and connect these sensors in a single circuit aside from these sensors. The experiment was performed in the apple orchard of Shimla, (H.P), India. Algorithms used for data capturing are presented in algorithm 1.

Algorithm 1: Data Capturing

1: Begin

2: While (NodeMCU(status) == "ON")
3: Temperature ←DHT22
4: Humidity ← DHT22
5: Altitude ← BMP180
6: Light ← BH1750
7: Data←{Temperature, Humidity, Altitude, Light}
8: End

4.2 Data Transmission

In this layer, data collected from IoT devices are transmitted to cloud server for further processing. For real-time data storage, this work used "Firebase". In this layer, the mobile application is also linked with this server which displays the real-time data over mobile application.

4.3 Disease Prediction and Recommendation

The paper employs fuzzy logic, specifically the Mamdani fuzzy inference system (MFIS), for predicting apple diseases. The system's operation is characterized by fuzzy rules that consist of linguistic variables (LV). These variables assume values within a term set that corresponds to real-world interpretations. The construction of MFIS encompasses the creation of a rule base (RB), a database (DB), and a method for defuzzification.The input to the proposed MFIS is a set of data $D = \{d_1, d_2, \ldots . d_n\}$. The $d_n$comprises input parameter temperature, humidity, altitude, and light intensity, i.e.,$d_n = \{d_{temp}, d_{hum}, d_{alt}, d_{light}\} | d_n \in [d_{min}^r, d_{max}^r] \subset R . d_{min}^r$termed as minimum and d_{max}^r is the maximum values for the given environemntal variables as presented in table 4. The rule base of an $F_i | F_i \in FU$ is composed of R fuzzy rules, where FU is the universe of all possible MFIS. Further, for a given set of inputs, the R for F_i is limited as $R_{min}^{F_i} \leq R_p^{F_i} \leq R_{max}^{F_i}$. The fuzzy rules $R_p^{F_i}$is represented as input fuzzy set $I_{F_i}(R_{F_i}^p, \mu_{F_i}^p)$ of $x$elements and output fuzzy set $O_{F_i}(R_{F_i}^p, \mu_{F_i}^p)$f of y elements.

In the given scenario, the inputs are $d_{temp}, d_{hum}, d_{alt}, d_{light}$, where the output is disease occurrence possibility as $d_{high}, d_{average}, d_{low}$.Therefore $|x| = 4 \; and \; |y| = 1$, respectively. The membership function,μ_{F_i} shows relation between $I_{F_i}(R_{F_i}^p, \mu_{F_i}^p)$and $O_{F_i}(R_{F_i}^p, \mu_{F_i}^p)$. The database, DB of $\mu_{F_i}$is evaluated according to Cauchy function, which is represented as:

$$\boldsymbol{F}_{(I_{F_i}, cent, h, s)} = \frac{\mathbf{1}}{\mathbf{1} + |\frac{I_{F_i} - s}{cent}|^{2s}} \qquad (1)$$

Where, $cent$= center of membership function
h= half-width of membership function
s = slope at the crossover point of the membership function.
The rule base is represented as:

$$R_{F_i}^p : IF \; I_{F_i}^{temp} is \; LV_{n_j^{tem}}^x \; and \; I_{F_i}^{hum} is \; LV_{n_j^{tem}}^x \; and \; I_{F_i}^{alt} is \; LV_{n_j^{tem}}^x \; and \; I_{F_i}^{light} is \; LV_{n_j^{tem}}^x \; THEN \; LV_{n_j^{tem}}^y$$

The article provides a selection of rules showcased in Table 5. The center of area or center of gravity (CoA/CoG) defuzzification technique, which is among the most commonly utilized, was chosen to obtain a clear output. To determine the fuzzified result, the centroid of all subsections within the resultant continuous membership function is pinpointed and then combined. The mathematical representation of the CoA defuzzification is as follows:

$$\boldsymbol{O}_{prob}^{Fi} = \frac{\int_{n_{min}^{pprob}}^{n_{max}^{pprob}} \boldsymbol{f(x).xdx}}{\int_{n_{min}^{pprob}}^{n_{max}^{pprob}} \boldsymbol{f(x)xdx}} \qquad (2)$$

Table 4. Fuzzy Rule Conditions [38][39]

Environmental Factor	Conditions	Possibility
Temperature	<18^0C	Low possibility of disease
	>18^0C	High possibility of disease
Altitude	<2500m (Low Hills)	High possibility of disease
	>2500<=3000 (Mid Hills)	average possibility of disease
	>3000 (High Hills)	Low possibility of disease
Humidity	<50%	Low possibility of disease
	>50%<=60%	Average possibility of diseases
	>60%	High possibility of disease
Light Intensity	<11000 lux (shady)	High possibility of disease
	>11000 lux (sunny)	Low possibility of disease

Table 5. Designed Fuzzy Rules

Temperature	Altitude	Humidity	Light Intensity	Fuzzy output
Low	Low	Low	Low	low
Low	Low	Low	High	low
Low	Low	Average	Low	Low
Low	Low	Average	High	Average
Low	Low	High	Low	Average
Low	Low	High	High	Average
Low	Average	Low	Low	Average
Low	Average	Low	High	Average
Low	Average	Average	Low	Average
Low	Average	Average	High	High
Low	Average	High	Low	Average
Low	Average	High	High	High
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High	Average	Low	Low	Average
High	Average	Low	High	High
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High	Average	Average	High	High
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High	High	Low	High	High
High	High	Average	Low	High
High	High	Average	High	High
High	High	High	Low	High
High	High	High	High	High

RESULTS AND DISCUSSIONS

Data Description

There are four stages in this development process: the experimental prototype, analysis of environmental variables, disease forecasting, and recommendations. The experimental prototype phase is focused on the initial setup and proper functioning of hardware components. Meanwhile, the analysis of environmental variables deals with collecting and examining environmental data before uploading it to a server. Central to this is the embedded system, built around the Node MCU, which communicates with a remote server. Sensors, which are mounted on a breadboard linked to the main microcontroller, facilitate data transmission. These primary sensors gather real-time environmental analytics and relay them to the system. The whole evaluation can be categorized into two parts: the deployment of an IoT-based system that incorporates sensors for humidity, altitude, light, and temperature; and data analysis at a remote server using software tools available on a mobile app. The data gathered aids in refining prediction outcomes.

Parameters Used

For result evaluation following parameters are used:

Response Delay: Time difference between start and end of execution is termed as response delay time, Res_{time}. Mathematically, it is represented as:

$$\boldsymbol{Res_{time}} = |\boldsymbol{T_{stop}} - \boldsymbol{T_{start}}| \quad \textbf{(3)}$$

Where, T_{stop}= Stop Execution time and T_{start}= Start Execution time.

Accuracy: Accuracy is the ratio between true prediction by total tested samples. Mathematically, it is represented as:

$$\boldsymbol{Accuracy} = \frac{\boldsymbol{TP + TN}}{\boldsymbol{Total\ Samples}} \quad \textbf{(3)}$$

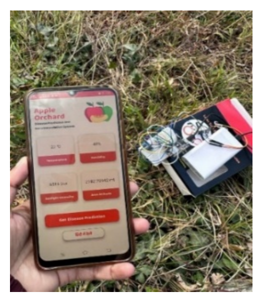
Where, TP= True Positive, TN= True Negative

Results Analysis

The producers of apples in Himachal Pradesh, as well as the relationship between disease development in apples, are both investigated in this article. The Himachal Pradesh apples producers' perspectives on climate change are presented. Apples are susceptible to a wide range of illnesses, the development of which is thought to be significantly influenced by temperature. In general, fungal diseases manifest themselves at lower temperatures, whereas the majority of infectious infections, in comparison to fungal infections, become more dangerous when exposed to exceedingly high temperatures.[19] During the growth phases of apple fruits, a multitude of diseases can manifest if the temperature ranges from 10℃ to 30℃[40] The progression of diseases is also impacted by humidity since it modifies the way infections take place. Rainfall and high relative humidity both contribute to the development of illnesses in multiple parts of an apple plant, including the fruit itself. Humidity levels in apple plants that are greater than 70% are ideal for the growth and infection of disease. core rot, brown rot, seedlings blight, and Powdery mildew are among the most common diseases that can be caused by high relative humidity in apples.[40] Himachal Pradesh is home to some of the most beautiful landscapes in the world. Apple trees are currently being cultivated at altitudes in Himachal Pradesh that are higher than 3,500 meters. The proposed system is put through testing with the Arduino IDE before the results of the analysis are analyzed. Below are some screenshots of the system in its tested state, which can be found in this section. In Figure 3, the data captured from each sensor are presented. Figure 3(a) represents the reading obtained from each sensor collected from different locations. Figure 3 (b) and figure 3(c) represent Realtime data collection and storage at the cloud server and its display on the mobile application. This helps in the Realtime monitoring of apple orchards.

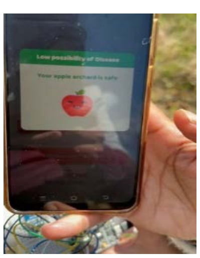
a. Real-time Experimental Site

b. Real-time Cloud Database

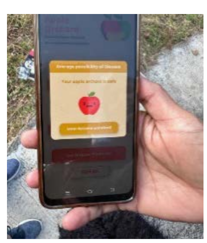


c. Real-time Environmental Factor Monitoring on App

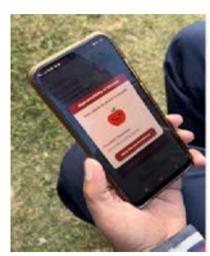
Figure 3. Real-time Experimental Setup



Prediction in High Light Intensity (Sunny)



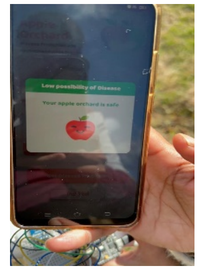
Prediction in High Light Intensity (Sunny) and Lower Altitude



Prediction in Low Light Intensity (Shady) and Lower Altitude

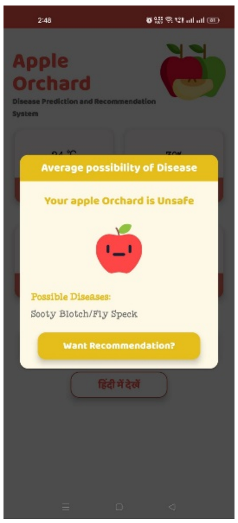
Figure 4. Some Examples of real-time Prediction

a. Verification of Apple Conditions with Apple Orchard's Professionals

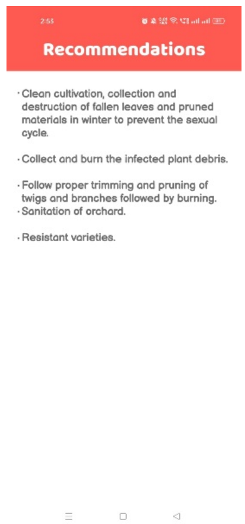


b. Verification According to Apps

Figure 5. Expert Verification for Disease Prediction



a. Prediction Results



b. Recommendations

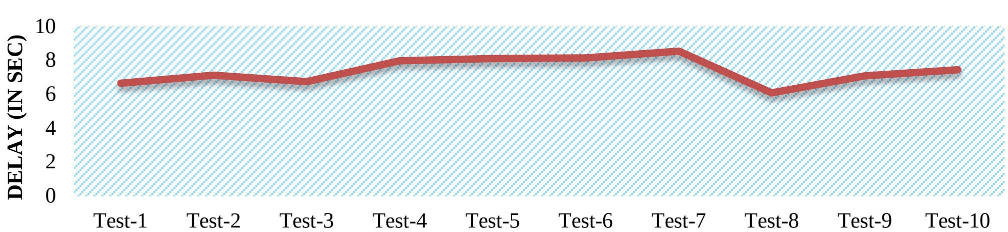
Figure 6. Recommendation Result for Disease Prediction

Figure 4 presents real-time prediction whose result is verified by native experts as presented in Figure 5. Figure 6 presents the prediction result of the app and its recommendations. Table 6 represents some samples of reading observed. Figure 7(a) represents the Res_{time}evaluation of the proposed system to estimate the time delay that occurred during data capturing. Similarly, Figure 7(b) represents the Res_{time}evaluation of the proposed system to estimate the time delay that occurred during data transmission and Figure 7(c) represents the $Res_{time}$for prediction and recommendation. Data samples were collected at different locations and their delay (in sec) was observed. The average delay for data capturing was observed to be approx. 7 sec. Whereas the average time delay for data transmission was approx. 4 sec. Whereas, the final prediction and recommendation show an average of 2 sec time delay.

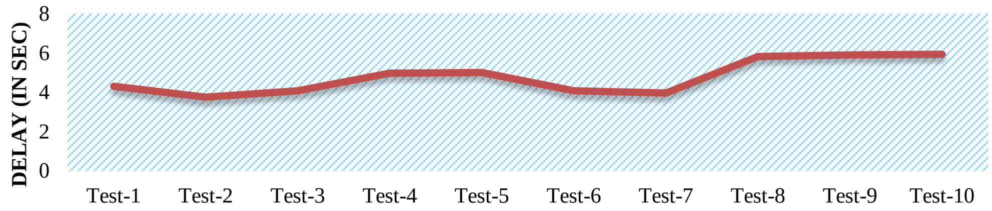
Table 6. Sample of Real-time Collected Data

Sample No.	Temperature	Humidity	Altitude	Light Intensity
1	25℃	59%	2146	6186 lux
2	26℃	60%	4234	5156 lux
3	25℃	64%	2354	4216 lux
4	27℃	69%	2325	6165 lux
5	25℃	73%	1353	6086 lux
6	26℃	54%	1235	3220 lux
7	28℃	78%	1478	3221 lux
8	24℃	46%	3438	6254 lux
9	25℃	64%	3566	6268 lux
10	26℃	79%	2357	3586 lux

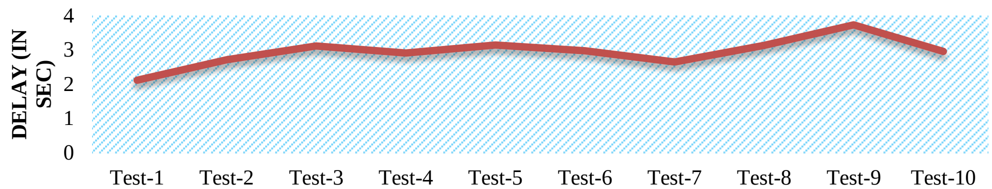
Below table 7 presents the accuracy of the proposed model. This accuracy was evaluated based on samples collected month-wise. The accuracy of disease identification varies considerably across the samples, ranging from as low as 50% to as high as 91.30%. The average accuracy is approx. 80%. This means that, on average, about 3 out of every 4 disease identifications are correct. The number of samples collected varies widely. This might influence the accuracy in some cases. Similarly, fig 8 presents the disease incidence throughout the year from Jan-Dec in Shimla orchards. From observation, apple scab was the most frequent occurrence as compared to other diseases. In conclusion, the disease identification method seems to be reliable on average. Fig 9 presents the accuracy comparison of the proposed model with the existing model and it was observed that the existing machine learning approach, SVM+NN[45] has achieved an average accuracy of 70%, and our fuzzy-based system has achieved an accuracy of 80%. Further investigation into these instances and refining the method might lead to even better accuracy rates.



a. Time Delay Occurred During Data Capturing



b. Time Delay Occurred During Data Transmission



c. Time Delay Occurred During Disease Prediction and Recommendations

Figure 7. Response Delay Evaluation

Table 7. Accuracy of the Proposed Methodology

Month	Samples Collected	Disease Identification	Correct Identification	Incorrect Identification	Accuracy
Jan	1032	48	38	10	79.17%
Feb	1056	36	32	4	88.89%
March	1142	24	21	3	87.50%
Apr	1442	41	32	9	78.05%
May	1756	89	71	18	79.78%
June	1544	45	37	8	82.22%
July	1342	23	21	2	91.30%
Aug	1767	87	74	13	85.06%
Sept	1098	72	62	10	86.11%
Oct	1043	10	8	2	80.00%
Nov	953	4	2	2	50.00%
Dec	1055	31	25	6	80.65%
		Average			76.88%

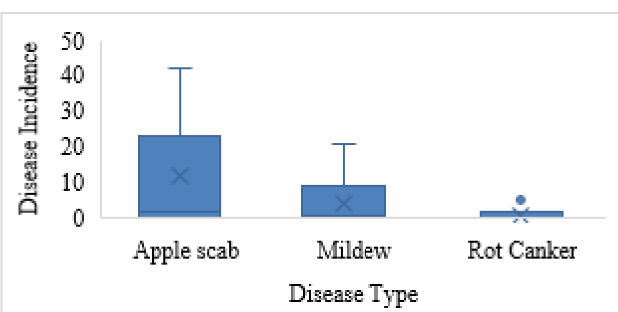


Figure 8. Disease Incidence

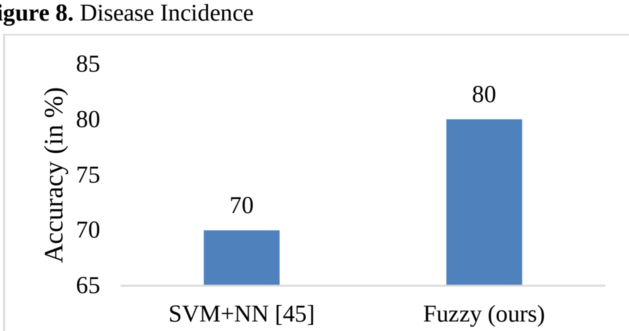


Figure 9. Accuracy Comparison

Table 8. Comparative State-of-art Features

Ref	IoT	MA	R_t	CS	Environmental Factors			
					Te	Hu	Pr	LI
[41]	×	×	√	×	×	×	×	×
[42]	√	×	√	×	×	×	×	×
[43]	√	√	√	×	×	×	×	×
[44]	√	×	×	√	√	√	×	×
[45]	√	×	√	×	×	×	×	×
Ours	√	√	√	√	√	√	√	√

IoT= Internet of Things Application, MA = Mobile Application, R_t=Realtime, CS= Cloud Services, Te= Temperature, Hu= Humidity, Pr= Pressure, LI= Light Intensity, √ = Feature Included, × = Feature Not included

The current state of the art is compared in Table 8, which may be found here. In Table 8, a comparison is made between the work that has been done by a variety of researchers and the work that has been done in the context of this study in the area of disease detection. The monitoring of diseases in real-time[41] is accomplished through the use of image-processing techniques rather than the identification of environmental parameters. Internet of Things (IoT) is utilized.[42] alongside a real-time system, for disease diagnosis by image processing; however, environmental elements are not taken into consideration. Researchers in the study[43] used image processing to detect disease, and one of the methods they used was the IoT. The other two methods were mobile applications and real-time systems. Researchers predicted the occurrence of diseases using the IoT by analyzing environmental factors such as cloud service, temperature, and humidity.[44] The Internet of Things and real-time analysis are utilized by Nagajyothi et.al.[45] as part of an image processing methodology for disease detection. In the current study, a combination of mobile applications, IoT, and real-time is used to predict the potential diseases that will emerge in future by determining all of the environmental factors, such as temperature, humidity, pressure, light intensity, and cloud service. This was accomplished by collecting data from mobile devices.

Conclusion

The proposed methodology successfully integrates IoT with real-time environmental monitoring to predict apple diseases in orchards. The use of advanced sensors, cloud storage, and the Mamdani fuzzy inference system proves effective in timely disease detection and recommendations. The system's minimal response delays in various stages emphasize its potential for real-world applications. Comparative analysis further establishes the superiority of this approach over existing methods, as it offers a comprehensive assessment of environmental factors. With the growing challenges in agriculture due to climate change and other factors, such a system can be invaluable in safeguarding crop health and ensuring sustainable agricultural practices. Future endeavors can explore the scalability of this system to other crops and regions, making it a universally applicable solution.

Conflict of Interest Statement

Authors do not have any conflict to declare for publication of this work.

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