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Machine Learning and Internet of Things based Fruit Quality Monitoring System: A Proof of Concept Implementation and Analysis

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Abstract: Food safety is imperative to avoid food borne diseases and to ensure the public health. Monitoring of perishable food products and early detection of degradation will avoid loss due to food wastage and ensures the freshness of food. In this scenario, remote monitoring of fruits during transportation from field to shelf can ensure the quality of fruit. Recent technological advancements like Internet of Things and Machine Learning (ML) has significant methodologies which can improve the fruit quality monitory process's cost and time efficiency. This paper describes the concepts, architecture, proof of concept implementation and results analysis of such a Fruit Quality Monitoring System (FQMS).
Keywords: Fruit quality, Bioinformatics, Internet of Things, Machine Learning, Deep Learning

I. INTRODUCTION

Food is the main energy source for the living being, intrinsically food quality and safety has been within the highest demand throughout the human history. The standard of food must be monitored, and it must be prevented from rotting and decaying because of atmospheric factors like temperature, humidity, and darkness. Therefore, it is necessary to put quality monitoring devices at food stores. These quality monitoring devices keep a watch on the environmental factors that cause or pace up decay of the food. Fruit contamination can occur within the production process, but also an outsized part caused by the inefficient food handling due to inappropriate ambient conditions when the food is being transported and stored. Therefore, the monitoring system must be capable of measuring temperature and humidity also, presence of foul smell from the fruits and pests inside the fruit during transport and storage is of prime importance [20]. There are technologies like Internet of Things (IoT), and Machine Learning (ML) are currently widely used in different fields. It has significant usage also on food quality monitoring and effective prediction of quality parameters. In this work, a sensor suite of couple of heterogeneous sensors for various domains and a camera unit is designed for sensing the condition of food during transportation and even after storage. IoT technologies are also used for facilitating remote monitoring of fruits. Machine Learning algorithms are used for classification and prediction of fruit's quality. We also implemented a user alert mechanism via messages whenever an emergency occurs. The rest of the paper is organized as follows: Section II describes the motivation and problem analysis behind this work. Section III provides the state of the art and detailed reporting of technologies behind the system. The proposed system concepts, its architecture and proof of concept implementation are given in Section IV. The result analysis is given in Section V and we conclude the paper with an outlook in Section VI.

II. MOTIVATION AND PROBLEM ANALYSIS

Monitoring the quality of fruits while they are stored in shops and when they are transported over different places are extremely important. The fruits can easily decay due to the variations in temperature, humidity and presence of certain gas content during storage and transportation, which can end in gastrointestinal disorder or food-borne diseases. Each fruit have different temperature, humidity levels to take care of their freshness. Also, when the fruits decay, it is often due to the bacterial presence, thereby the fruit produces a foul smell. When fruit goes bad and starts to become pungent, it's most frequently due to the expansion of spoilage microbes like bacteria, yeasts and mold. Odors can come from two sources: chemicals that are released from the food because the microbes decompose it, or chemicals produced directly by the microbes themselves. Fruits produce ethylene, a chemical that causes sudden and dramatic ripening, which may cause a stronger odor [21]. In order to maintain the freshness, usually the cultivators or sellers sprays more amount of harmful chemicals into it. But eventually after couple of days, the fruit decays. These freshness chemicals are really harmful. If they do not use any kind of chemical fertilizers or pesticides, it can cause rotten fruits and wastage. Thus, it can cause huge loss in income.

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It is very difficult to ensure the freshness of the fruits, since it needs to be monitored 24 hours by labourers checking them one-by-one. Thus, causes a lot of manual work. Time and cost-efficient monitoring methods are one another challenge to address in the fruit quality monitoring domain. There exists multiple problems and multiple challenges in this field, as shown in Fig.1. There is a need of an optimized and efficient solution to solve these multiple problems. Conception, design, proof of concept implementation, and performance analysis of such a Fruit Quality Monitoring System (FQMS) is our objective in this work.

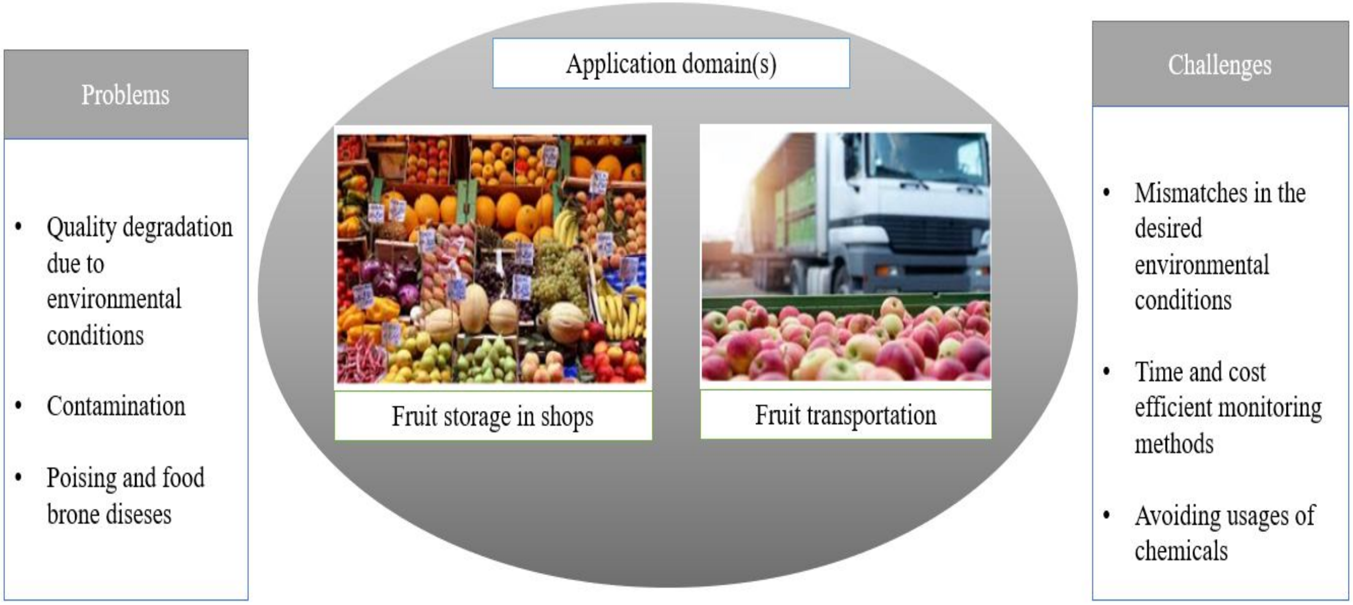

Fig. 1 Motivating example and challenges

III.STATE OF THE ART

In this section, we provide a review of the related works in this field and provide an overview of technical solutions used for this work.

A. Related Works

In the literature, we have found a few related works. In Table 1, we summarize the overview of the different available work and provided comparison of different technologies used.

TABLE I: Comparison of Related Works

Ref	Summary of contributions	Comparison of technical solutions used			
		Sensor Tech.	IoT Tech.	ML Tech.	Any other Tech
[1]	Efficient food storage using sensors, android and IoT • Advantages: It is an efficient and simple method. It helps to identify the temperature, humidity and other factors also helps to control these factors. • Disadvantages: There is a chance for the destuction for this sensors during big accidents, Loss of network.	Temperature, humidity, smoke, light dependent sensors	Renesas microcontroller (RL78 series)	-	GSM
[2]	An intelligent IoT based food quality monitoring approach using low cost sensors • Advantages: It can prevent food from fast decay, low cost and efficiency • Disadvantages: Need huge data set for better evaluation and maintenance may be difficult.	Temperature, humidity, gas, pressure sensors	Ardunio Mega 2560	-	Andriod Application

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[3]	Deep feature representation with Stacked Auto-Encoder and Convolutional Neural Network for Hyperspectral imaging based detection of cucumber defects • Advantages: This model on easy the decision making, and reducing computational complexity. It is not labor intensive and time consuming compared to conventional methods. • Disadvantages: It is difficult to test the model during transportation with spectroscopy.	-	-	CNN-SAE algorithm	Spectral imaging
[4]	Fruit Disease Prediction Using Machine Learning Over Big Data • Advantages: This system will be cheaper than the existing system. It considerably saves Query retrieval time. Map Reduce algorithm which will increase efficiency. • Disadvantages: Dataset is less to perform classification.	-	-	SVM algorithm	Image Processing
[5]	Meat Monitoring System Using Machine Learning and IoT • Advantages: Monitoring food using sensors can identify the type of the food and its freshness. • Disadvantages: Complex and need better scheme for analysing the system every time.	IR, Electro-chemical sensors	Arduino	MAX_MAE alogrithm	Andriod application, Bluetooth low power beacon

B. Sensor and IoT Technologies for FQMS

Table. II: Comparison of different IoT Technologies suitable for FQMS

Requirements	Specific Unit	Remarks
Suitable Sensor Units for FQMS	Temperature and humidity sensor (DHT 11 Sensor)	These sensors are commercially available and can be either used as a sensor or as a module to integrate with the sensor's microcontroller unit.
	Gas Sensor (MQ5 Sensor)	
	PIR sensor	
Suitable Microcontroller Platforms for FQMS	Raspberry Pi	Sine the FQMS sensor platform needs to perform many data process operations via machine learning algorithms and need to interface with wireless connectivity module a reasonably powerful microprocessor platform is suitable.
	Arduino	
	Beagle board	
Suitable Radio Communication platforms for FQMS	Short Range Wireless Connectivity such as IEEE 802.11 variants and IEEE 802.15.4 variants.	Wireless connectivity is important to send the processed data to the back end and to the customers to deliver the target service of FQMS. For this purpose, depends on various technical requirement of wireless connectivity such as range, power consumption, licensing, and cost there are different choices. However, for food storage use case the Short-range wireless connectivity is the best and for transportation either cellular or LPWAN connectivity is used.
	Cellular communication 2G/3G/4G/5G	
	Low Power Wide Area Networking (LPWAN) Technologies (LoRaWAN, SigFox, Narrow Band IoT, LTE-M)	

IoT technologies used for monitoring application like fruit quality, mainly consist of 3 elements. (1) Sensor unit to sense various parameters. (2) A microcontroller unit for processing the sensed values and aggregating the data before transmission, (3) Radio Communication unit, which is responsible for transmitting the pre-processed data from the micro controller to final destination (a receiver which operate together with mobile phone, PC, or a cloud platform).

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C. Machine and Deep Learning algorithms used for FQMS

In this section gives an overview of ML and DL algorithms suitable for FQMS.

1) *Random Forest Algorithm:* Random forest is a supervised learning algorithm which is used for both classification as well as regression. As we know that a forest is made up of trees and more trees means more robust forest. Similarly, random forest algorithm creates decision trees on data samples and then gets the prediction from each of them and finally selects the best solution by means of voting. It is an ensemble method which is better than a single decision tree because it reduces the over-fitting by averaging the result. The working of Random Forest algorithm is explained with the help of following steps (which is summarized in Fig.2):

a) Start with the selection of random samples from a given dataset.
b) This algorithm will construct a decision tree for every sample. Then it will get the prediction result from every decision tree.
c) Voting will be performed for every predicted result.
d) Select the most voted prediction result as the final prediction result [18].

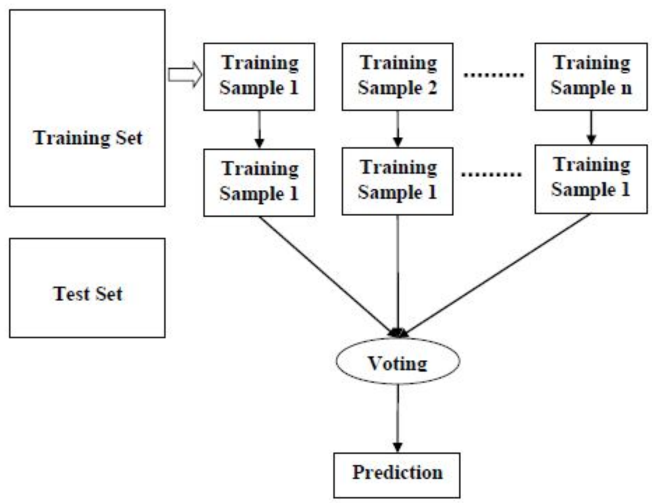

Fig. 2 Working Diagram of Random Forest Algorithm [18]

2) *Support Vector Machine(SVM):* The objective of the support vector machine algorithm is to find a hyperplane in an N-dimensional space (N — the number of features) that distinctly classifies the data To separate the two classes of data points, there are many possible hyperplanes that could be chosen. Our objective is to find a plane that has the maximum margin, i.e. the maximum distance between data points of both classes. Maximizing the margin distance provides some reinforcement so that future data points can be classified with more confidence (refer Fig.3) [14].

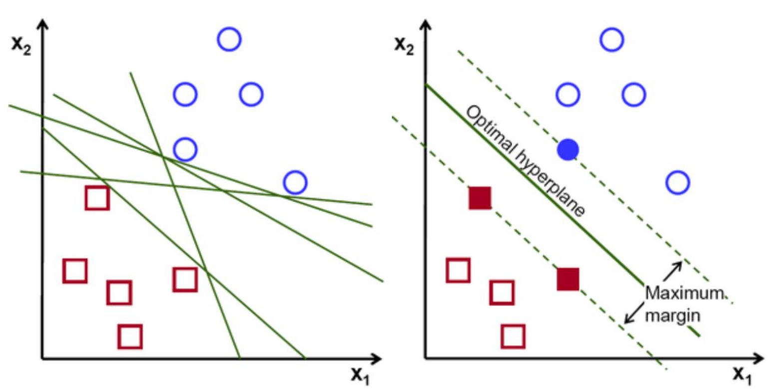

Fig. 3 Possible hyperplanes [14]

3) *Convolutional Neural Networks (CNN):* In deep learning, a Convolutional Neural Networks is a class of deep neural networks, most applied to analysing visual imagery. In the CNN, the layers are organized in 3 dimensions: width, height and depth. Further, the neurons in one layer do not connect to all the neurons in the next layer but only to a small region of it. Lastly, the

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final output will be reduced to a single vector of probability scores, organized along the depth dimension [19]. CNN is composed of two major parts:

a) Feature Extraction: In this part, the network will perform a series of convolutions and pooling operations during which the features are detected.

b) Classification: Here, the fully connected layers will serve as a classifier on top of these extracted features. They will assign a probability for the object on the image being what the algorithm predicts it is [23].

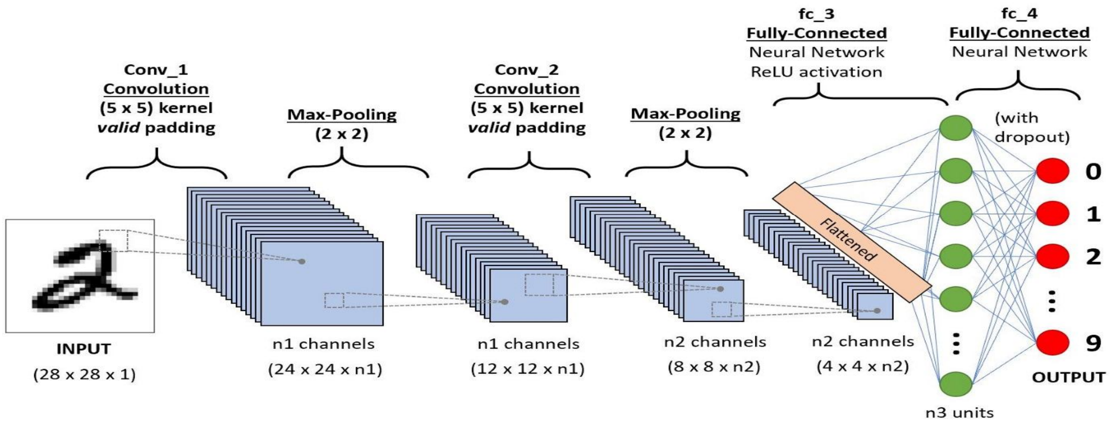

Fig. 4 A CNN sequence to classify handwritten digits [22]

IV. FQMS- CONCEPTS, ARCHITECTURE, AND IMPLEMENTATION

The Fruit Quality Monitoring System is a framework based on IoT and Machine Learning technologies.

A. Concepts and Architecture of FQMS

The proposed system can be basically divided into three sub modules, a detailed architectural overview is given in Fig .5.

1) *IoT module*: The embedded part of the system consists of Raspberry Pi 3B+ microcontroller. The code for the functioning of camera and ML algorithms are places into class 10 memory card, which has been inserted in the Raspberry Pi. The expected range of threshold values of parameters (temperature, humidity, methane, PIR) are stored in the dataset created using excel. Using DHT11[8], MQ5[9], PIR sensors [10], the parameters of fruits are measured [1][2] and is given to the ML algorithm like Random Forest algorithm or Support Vector Machine (SVM) [4].
2) *Machine learning module*: We are using 3 machine learning algorithms. Random forest classifier or SVM, which is used to generate prediction from sensor data. Convolutional Neural Networks (CNN) which are used to generate prediction from image data [3].
3) *Alert Module*: In this module, the user gets message whether the fruit is good or not. It will provide alert for each sensor parameter and images. With the help of GSM module, the output from sensor and images are given to user's mobile through messaging. The DHT 11 sensor [8], for the detection of variation in the temperature and humidity. The value of the temperature is given in degree Celsius (°C) and humidity in percentage (%). Also, for the detection of the production of methane gas and presence of any kind of living organism like pest, we use MQ5[9] and PIR [10] sensors, respectively. The result of PIR and MQ5 is obtained as 0 or 1. The detected value from the sensors will be given to the algorithms. Then test data-set value is compared with the threshold value in the training dataset. If the value is not in the threshold range it will be classified as bad, else good. Then the result will be alert as a message to the user's phone. If the sensor detects variations in the range of temperature or humidity values, the prediction is generated using Random Forest algorithm. This alert is generated as a message. When the MQ5 sensor detects the gas it also gives the value 1 and the message will be alerted as:" gas is detected". Otherwise the value will be 0. If the PIR sensor detects any pest, the value will be 1 and the message will be alerted as:" pest is detected". Otherwise the value will be 0. Next, the image of the fruit is captured using webcam. Then the image will be given to the deep learning algorithm called Convolutional Neural Network or CNN. The test image is compared with the training dataset using the CNN, it predicts the image as, i.e., good, or bad. It also shows the chances of the fruit to be good or bad by giving a score. Also. the result will be alert to the user. The predictions conclude whether the fruit is fresh or not. The status of the fruit is notified to the user through message with the help of GSM module.

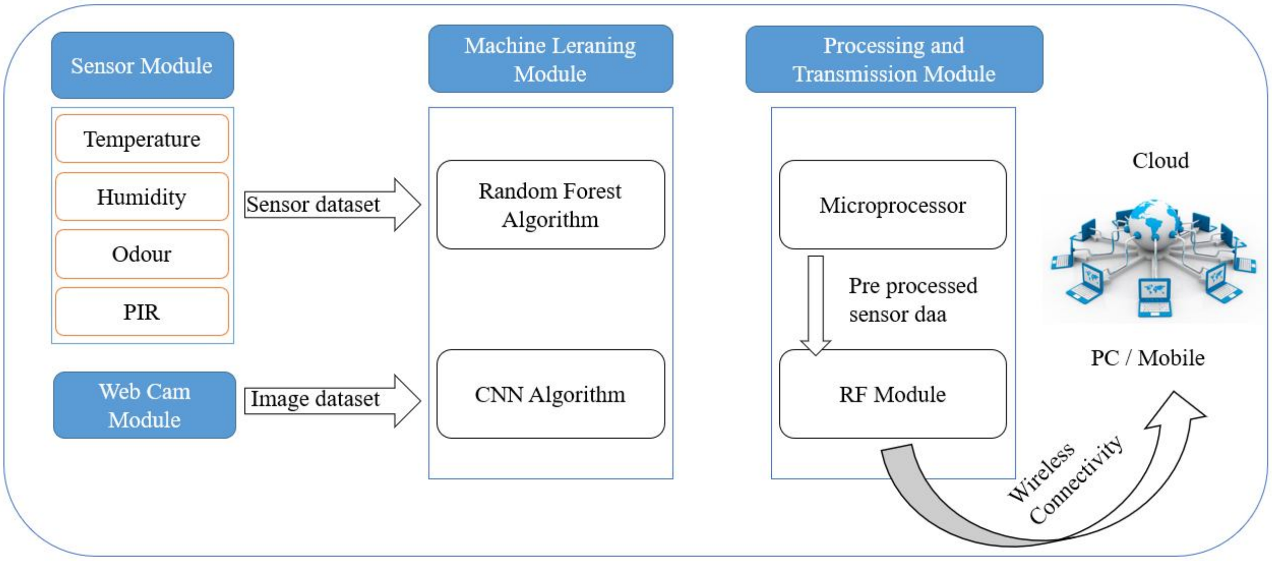

Fig. 5 Architecture of Fruit Quality Monitoring System

B. Proof of Concept Implementation

An overview of Implemented system is given in Fig.6. Along with the integration and set up of required hardware units', the major implementation was performed on the software level in terms of the following.

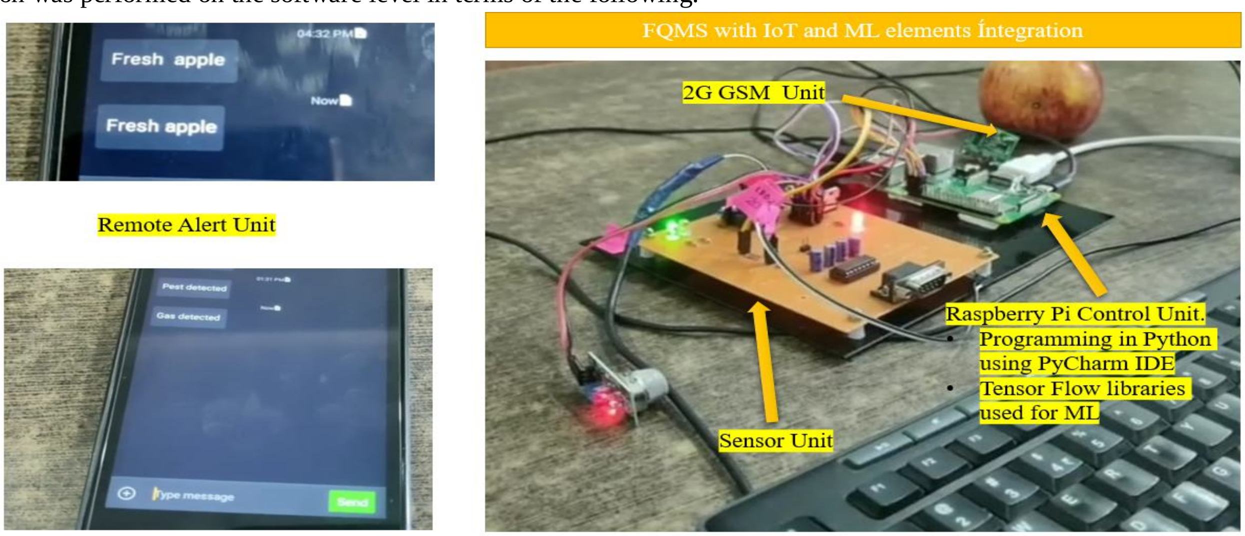

Fig. 6 Proof of Concept Implementation Overview

1) *Freshness Identification:* Each fruit have different temperature and humidity levels to maintain freshness. Also, when the fruits decay, it can be due to bacterial presence thereby produce a foul smell. When fruit goes bad and starts to become pungent, it is most often due to the growth of spoilage microbes such as bacteria, yeasts and mold. Odours can come from two sources: chemicals that are released from the food as the microbes decompose it, or chemicals produced directly by the microbes themselves. Fruits produce ethylene, a chemical that causes sudden and dramatic ripening, which can lead to a stronger odour [21]. Based upon the output of the DHT11[8] sensor the freshness of the fruit is predicted using monitoring values of temperature (in °C) and humidity (in %). If the output of temperature lies between 0°C-35°C, then the fruit is very fresh. If it's less than 0°C, then the fruit is not really fresh but it can be consumed. If it is above 35 °C, then the fruit is unfit to be consumed. If the output of humidity lies between 45% -70%, then the fruit is very fresh. If it less than 45% or above 70%, then the fruit is unfit to be consumed. If the output from MQ5 gas sensor [9] is 1, then there is presence of gas. Otherwise if the value is 0, then the gas is absent. If the output from PIR [10] sensor is 1, then there is presence of pest. Otherwise if the value is 0, then the pest is absent.

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2) *Construction of dataset*: For the sensor values, we create a excel table as dataset which has 5 columns: temperature, humidity, methane, PIR, status. If the output from all sensors are in threshold value, then status is 1. Otherwise if any one of the sensor values vary from threshold, then the status is 0. For image dataset collection, the training dataset and the testing dataset is obtained by capturing images from webcam and a mobile phone [6][7]. Approximately 13,599 images contain fruits like apple, orange and bananas [13]. The images include fruits which are not affected by disease that is a normal fruit and images of diseases fruits with the degree of disease affected being low to high. Three stages of diseased fruit are considered namely low medium and high. The low-level diseased fruits contain few spots on the surface of the fruit. The medium level diseased fruits contain more spots which are darker. The high-level diseased fruits contain cracked surface and the colour of the fruit been changed [21].

V. RESULT ANALYSIS

The outputs from sensors and camera is given to the machine learning unit as its test dataset. For this, we have used ML algorithm which will identify the state of the fruit from raw, ripe, or rotten. The algorithm compare the test and training data-sets and they create predictions. The predictions can be fresh or damaged fruits. If it is damaged, it notified to the seller through a mobile application.
We have analyzed the accuracy of our implementation by taking various categories of measurements and analysis as follows.

A. *Measurement of Sensor values under various atmospheric conditions*

To analyze the accuracy of sensor values we have performed measurements under different atmospheric conditions. If the output of temperature (from DHT11 sensor) lies between 0°C-35°C, then the fruit is very fresh. If it's less than 0°C or above 35°C, then the fruit is unfit to be consumed. If the output of humidity (from DHT11 sensor) lies between 45% -70%, then the fruit is very fresh. If it less than 45% or above 70%, then the fruit is unfit to be consumed. If the output from gas sensor (from MQ5 sensor) is 1, then there is presence of gas. Otherwise if the value is 0, then the gas is absent. If the output from the PIR sensor is 1, then there is presence of pest. Otherwise if the value is 0, then the pest is absent. Output from these 4 parameters decides the status of fruit (fresh or rotten). The results given in Table. III shows the accuracy of the system.

Table. III: Sensor Value Measurements

Atmospheric Condition	Measure Value			
	Temperature	Humidity	Odour	Pest
Under normal condition	25	51	1	1
Near to the heater	125	23	0	0
In a fridge	-18	100	0	0

B. *Analysis of precision of ML algorithms*

We have performed the behavior analysis of our ML algorithm by taking different prediction conditions into account as shown in Table IV and it showed a reliable performance.

Table. IV: ML algorithm precision analysis

Quality prediction Condition	ML Algorithm Behaviour Analysis		
	Detected	Not detected	Partially detected
Under normal condition	Yes		
Near to the heater	-	-	Yes
In a fridge	-	-	Yes

C. Analysis of IoT Communication accuracy

We have performed the IoT communication analysis of our system by taking different conditions which may affect communication quality into account as shown in Table V and it showed a reliable performance. We have used a GSM RF module, so it showed a good performance in range. However, it has significant energy consumption to reduce that onew wireless technologies like LPWAN need to be used in future for an efficient solution.

Table. V: Communication behaviour analysis

IoT Communication Alert Condition	Communication Behaviour Analysis		
	Successful	Not Successful	Other Remarks
Under normal condition	Yes	-	-
Moving around with a car	Yes	-	-
By hiding the module inside the fridge	Yes	-	-

VI. CONCLUSIONS

In this paper, we proposed fruit quality monitoring system that is used to predict the freshness of fruits. The identification of fruit freshness will help the user to decide whether it is consumable or not. This method will help in reducing human labor and loss of income due to rotted fruits. Also enables to gain trust among the customers. The method can only help to find out the external changes in fruit using the camera. The IoT-based online monitoring approach using smart sensors can address the critical needs of reducing fruit waste, increasing transportation efficiency, and tracking fruit contamination. Based on the monitoring of the fruits before transportation, during transportation and while storage with the help of the machine learning it founds that there is any diseases in the fruits then they will be classified as errors using the CNN and Random Forest classifier. Based on the result from the CNN and Random Forest algorithm the system categorize fruit with contamination and healthy fruit. The alert message is sent to the driver of the vehicle and owner.

In future, if we could adapt the method of spectroscopy, it can easily identify the internal defects of fruits. Spectroscopy is the study of the interaction between matter and electromagnetic radiation [12]. We also plan to integrate more LPWAN technologies and IoT services to optimize various aspects and to improve the overall efficiency of the system.

VII. ACKNOWLEDGMENT

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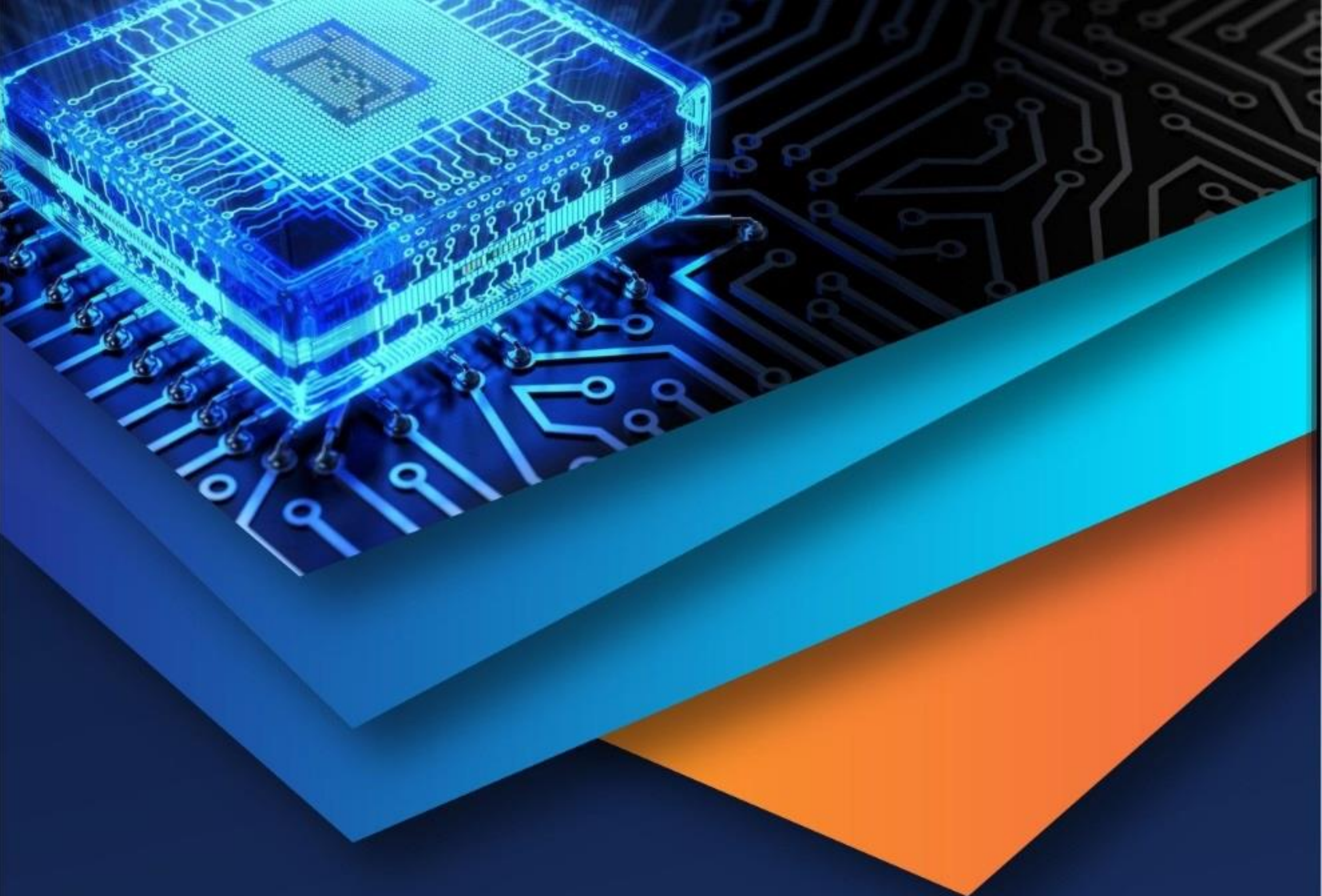

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