IoT Based Fruit Quality Inspection and Lifespan Detection System

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***Abstract*—Fruits are an essential source of nutrients, but their quality depends heavily on their freshness and shelf life, which can be impacted by various external factors. This paper presents a comprehensive study on the decay of fruits and the development of a decay detection system that uses Raspberry Pi Pico, DHT-11 sensor and MQ-4 methane gas detector sensor, data storage, and Machine Learning (ML) algorithms to accurately predict the expiration date of fruits. The proposed system focuses on measuring temperature, humidity, and methane gas emissions from the fruit, which are transmitted to a local database using NodeMCU ESP8266. The collected data is then used to predict the expiration date of the fruit with high accuracy and reliability. The system is cost-effective, user-friendly, and can be useful in warehouses, cold storage, and food quality inspection sectors. With further research and development, the proposed system can be extended to detect the lifespan and expiration of other perishable items, thus providing a comprehensive solution for food preservation and safety.**

***Index Terms*—IoT(Internet of Things), Raspberry Pi Pico, Methane Gas Sensor (MQ4), Embedded System, Machine Learning (ML).**

I. Introduction

Fruits are a vital component of a healthy diet, providing essential macro-nutrients and micro-nutrients such as vitamins, minerals, and fiber. However, the quality of fruit is highly dependent on its freshness and shelf life, which can be impacted by various factors such as temperature, humidity, and exposure to microorganisms. When fruits begin to rot, they not only lose their nutritional value but can also become breeding grounds for harmful bacteria and fungi, which is possibly dangerous to the well-being of humans.

Approximately 14% of the world's food is lost after harvest, up to but not including the retail stage of the supply chain, and an additional 17% is wasted in retail and at the consumer level. Food loss and waste contribute to 8–10% of total world GHG emissions, contributing to an unstable climate and catastrophic weather events like droughts and flooding. According to the 2030 Agenda for Sustainable Development, and more especially SDG 12, Target 12.3, worldwide per capita food waste at the retail and consumer levels, as well as food losses in the production and supply chains, must be reduced in half [1].

As shown in figure 1, a massive amount of food spoilage happens due to fungi, bacteria, and other microbial agents in several sections of the food preservation process [2]. If spoiled food can be detected in the early post-harvest section, then we can conserve more food items in a cost-effective manner. Hence, the novel approach of this paper is to introduce an IoT-based food quality inspection and early decay detection system while minimizing expenses to refrain from food loss, thus ensuring food freshness and an adequate amount of food preservation to meet future demands. The proposed system is a promising approach to monitoring fruit decay and accurately predicting expiration dates using advanced technologies such as sensors, data storage, and Machine Learning (ML) algorithms.

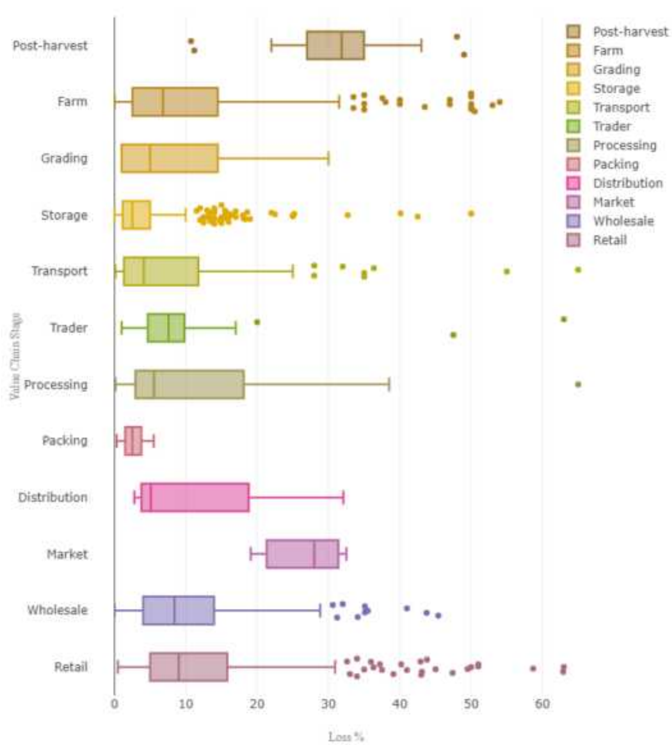

Fig. 1. Graphical Representation of Losses Across Value Chain Stages

In this paper, we provide a comprehensive overview of the existing systems used to detect fruit decay and predict their shelf life. The accuracy of our proposed method is significantly higher than that of the existing systems, with a success rate of over 75% in detecting fruit decay. One of the key advantages of our proposed method is that it is scalable, cost-effective, and user-friendly, making it ideal for fruit storage and transportation. Figure 2 demonstrates the assemblation of proposed system.

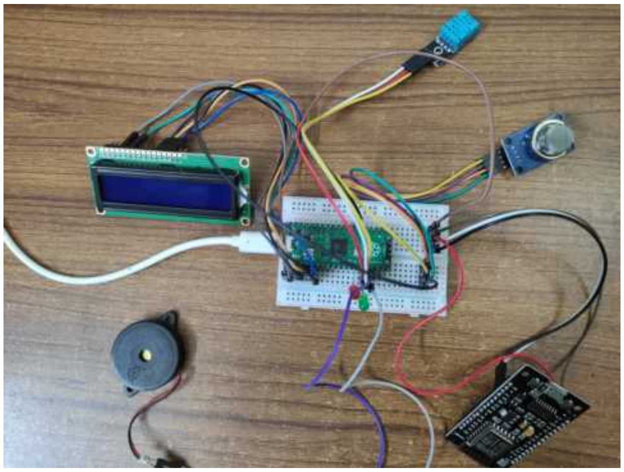

Fig. 2. Fruit Quality and Lifespan Detection System

In conclusion, our proposed method for fruit decay detection and prediction is a significant step forward in food preservation and safety, improving accuracy and reliability. It can be extended to other perishable items, providing a comprehensive solution for food preservation and safety.

II. Literature Review

Many researchers have proposed their novel approaches for detecting food freshness using several machine learning algorithms or sensors. Li et al [3], represented and analyzed 300 'Xuxiang' kiwifruit in order to observe the lifespan including the rotting process in cold storage (2° C) using RGB recognition software. Kathirvelan et al [4], highlighted IR thermal emission based ethylene gas sensor detects ethylene accurately by absorption of IR across the fruit's wavelength.

Chakraborty et al. [5], proposed a model to prevent the propagation of rottenness using CNN, on a Kaggle data set for achieving the highest accuracy rate of 99.46%. Megalngam et al. [6], used artificial intelligence along with image processing by CNN, k cluster algorithm, and HSV that can detect the spoilage percentage of food. Goel et al [7], develop an algorithm that combines three algorithms of MFA, PSO, and GSA to detect rotten food and this hybrid algorithm contains an 83.33% accuracy rate.

Tian et al. [8] proposed a new technology called Hyperspectral Transmittance Image to detect early decaying process caused by Penicillium Spp. In another research paper, Hemamalini et al. [9] used image processing techniques with k-means clustering, Support Vector Machine (SVM) and Gaussian elimination method to remove noise from collected photos. Karthickeyan et al. [10] combined Object Detection Algorithm YOLO and Convolutional Neural Network (CNN) for identifying spoiled areas on food skin. Chen et al. [11] introduced a new cost effective approach of biodegradable and disposable colorimetric geometric barcode sensors to detect rotten food. Paul et al. [12] proposed a new approach that can be easily implemented in refrigerators.

R. Torres-Sanchez et al. presented a real-time monitoring system utilizing electronic nose technology and Machine Learning (ML) algorithms to estimate the shelf life of fruits and vegetables [13]. Moreover, E. Sonwani et al. presented the use of artificial intelligence to detect and analyze food spoilage to enhance food safety [14]. Furthermore, K. Jaspin et al. suggested a real-time surveillance system that uses computer vision techniques to recognize the stages of vegetable and fruit maturity and detect infections [15].

J. S. Tata et al. proposed a real-time quality assurance system that applies both image processing and Machine Learning (ML) to recognize and classify defects such as bruises, cuts, and rot [16]. D. M. Bongulwar [17], presents a deep learning approach for fruit identification, which can be used to automate fruit sorting and grading processes.

K.A.Ahmad et al. classified star fruit ripeness using artificial neural networks with 97.33% accuracy [18]. In contrast, Indrabayu et al. used MultiClass Support Vector Machine (SVM) with Radial Basis Function (RBF) kernel function to classify fruit ripeness [19]. Fatma M. A. Mazen & Ahmed A. Nashat suggested methods based on HSV color, brown spot development, and texture inspection of fruit (eg. Banana) [20].

J.J Jijesh et al. added that CNN is the most accurate method for extracting features of fruits, compared to SVM and KNN [21]. Shalini Gnanavel et al. developed a detection sensor that can detect ripened fruit and indicate the level of hazardous substance, with an efficiency of 91% [22].

Anuja Bhargava & Atul Bansal discuss various algorithms proposed for fruit and vegetable quality inspection [23]. Anjali N et al. discusses the visual sensing techniques are the most effective and efficient methods for detecting defects in fruits and vegetables [24]. Mahdieh Mostafidi et al. discuss five main risks associated with primary production environmental and wildlife factors, fertilizer and pesticide use, irrigation water, worker and equipment hygiene, and contact levels [25]. Renuka N et al. optimized the architecture of an orange fruit classification system to achieve 8% success rate with fewer hardware resources [26]. V. G. Narendra & Ancilla J. Pinto propose algorithms to detect external defects in vegetables and fruits according to their morphology, texture, and color, with 87% accuracy [27].

Gogula et al. used MQ-4 gas sensor to detect Methane gas whereas Sahu et al. used Raspberry Pi and Machine Learning (ML) algorithms to detect alcohol, hydrogen, benzine, and LPG [28], [29]. Balaji et al. proposed a method to detect fruit and vegetable spoil systems [30]. Moreover, Abasi et al. developed a portable optical device to determine apple ripeness whereas Ramya et al. used image processing and cloud computing to detect fruit diseases [31], [32].

III. Proposed System Methodology

A rotten fruit emits gasses, Methane and Ethylene, the decay rate also depends on some parameters such as temperature, humidity. If we get all these values recorded then we can provide a prediction to how long the fruit will last by applying the decay rate formula. As a fruit decay it starts to emit methane gas, the amount of emission of methane gas is increased with the decayed percentage of the fruit, there is an initial amount of emission when the fruit starts to decay and a final constant rate of emission when the fruit is completely decayed, and the decay rate no longer increases. The decay rate of a rotten fruit is determined by the amount of methane it emits, increasing with the decayed percentage. Figure 3 represents the block diagram of the proposed system.

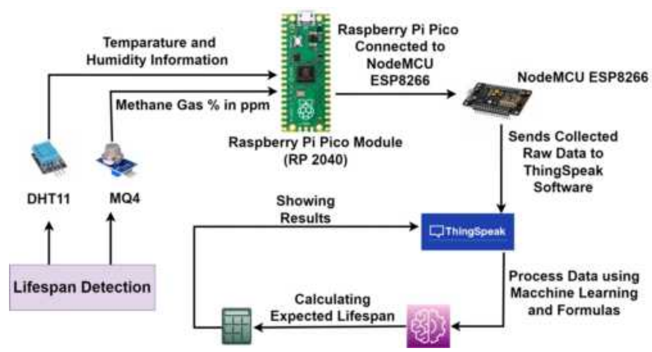

Fig. 3. Block Diagram of Lifespan Detection System

DHT11 sends humidity and temperature information to IoT based app, which is connected to a micro-controller Raspberry Pi Pico and NodeMCU ESP8266. The IoT based app stores the data in a database and to calculate the life expectancy applies the Machine Learning (ML) algorithm. The IoT based app then shows the raw data and lifespan. Sensors are connected to Raspberry Pi Pico and NodeMCU ESP8266 to measure temperature and humidity.

To measure Methane gas emission, we can use the sensor MQ-4 to detect the amount of gas that is emitted. Also, DHT-11 sensor is used to measure the temperature and humidity. These two sensors are connected to the Raspberry Pi Pico module, along with NodeMCU ESP8266 to transfer the data received over to the wireless network.

The Raw Data transmitted from ESP8266 is stored in a database and retrieved using Express JS, which creates an API called Front-End JavaScript. The algorithm checks the lifespan remaining and raises a warning if necessary, and the data is presented to the user via a Front-End Website.

$$lifespan = \frac{humidity}{100.0} * (e^{(0.05*(temperature-20.0))}) * \frac{\textit{lifespan constant}}{\textit{methane emission}} \tag{1}$$

The equation is derived from several variables that correspond to lifespan changes and the Fruit decay constant, which is divided by methane level. The threshold of temperature is 20, which means at 20°C the calculation is $(t-20)$ and the exponential rate is $(e^{(0.05*(t-20))})$. The decay rate of fruit decreases with increasing humidity, the humidity is measured in percentage so to make it decimal we have to divide it by 100. Temperature increases life expectancy exponentially, humidity decreases with increasing humidity, and the lifespan is varied by the rate of each other until the threshold value is reached.

Some related equations after going through several literature reviews are as follows:

Sensitivity is the fraction of true positives that are correctly detected. It relates to how successfully a test can identify positive outcomes.

$$Sensitivity = \frac{TP}{TP+FN} \tag{2}$$

Here, TP is termed as True Positive and FN is termed as False Negative [7].

The degree of specificity is defined by the accuracy with which negatives can be appropriately recognized. The challenge here is detecting negative outcomes.

$$Specificity = \frac{TN}{TN+FP} \tag{3}$$

The variables TN and FP in this equation stand for True Negative and False Positive, respectively [7].

Analyzing accuracy rate using TP/TN,

$$AccuracyRate = \frac{TP+TN}{TP+TN+FP+FN} \tag{4}$$

Furthermore, this equation provides the food spoilage detection more accurately [7].

Our proposed system reduces food waste and promotes health and sustainability. Our innovation in this project is, we have found a formula for calculating the lifespan of the fruit which have been never implemented before.

IV. System Design and Simulation

The core principle of the proposed system is to introduce a cost-effective method that can detect the shelf life of fruits and vegetables both inside and outside of cold storage. By accurately identifying the ripeness of fruits and vegetables and notifying workers before they spoil, this system can help minimize food waste.

In addition, by decreasing food spoilage, it can help ensure that consumers have access to fresh and healthy produce. It can help prevent consumers from eating spoiled fruits and vegetables, which might be risky for their well-being. This system is an innovative application of machine learning technology with the potential to revolutionize the supply chain, reduce waste, and focus on promoting health and sustainability.

This project aims to detect the lifespan of fruits and get an idea of their expiry date. DHT11 was attached to the Raspberry Pi Pico to measure Temperature and Humidity readings, and MQ4 was connected to the Raspberry Pi Pico to measure Methane gas emission. Using Fritzing simulator we created the circuit diagram of the proposed system that detects lifespan of fruits inside or outside of warehouses. Figure 4 represents the circuit diagram of the proposed system.

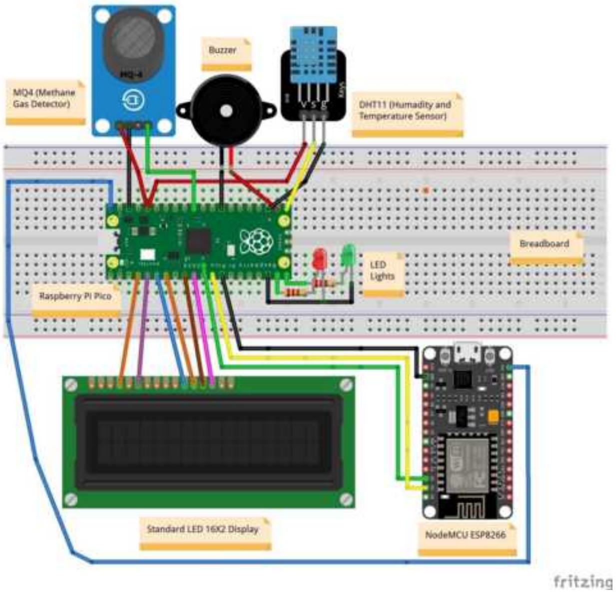

Fig. 4. Circuit Diagram of Proposed System (Fritzing)

V. Hardware Development and Testing

Our objective is to introduce a budget-friendly effective early food spoilage detection system to detect the lifespan of fruits and vegetables for ensuring the supply of fresh products to consumers. Table 1 displays all of the system's components' parameters.

TABLE I
TABLE OF SPECIFICATIONS

Serial No.	*Component Used*	*Quantity*
1	Raspberry Pi Pico (RP 2040)	1
2	MQ4 - Methane Gas Sensor	1
3	DHT11 - Temperature and Humidity Sensor	1
4	Breadboard	1
5	NodeMCU ESP8266	1
6	Power Supply (5V, 2A)	1
7	LCD 16*2 display	1
8	LED Lights	2
9	Buzzer	1
10	Connecting Wires	1

DHT11 and MQ4 are connected to the Raspberry Pi Pico to collect data on Temperature, Humidity and Methane gas emission. DHT11 has 3 pins and MQ4 has 4 pins. These two sensors can collect data on the fruit.

The NodeMCU ESP8266 is a SoC microchip integrated with a TCP/IP protocol stack used for IoT based embedded applications development. The Vin is connected to the Raspberry Pi Pico at pin VBUS, D1 and D2 are connected to pin 8 and 9, and the G pin is connected to the Pico at GND.

The LCD 16*2 display is used to display the condition of the fruit. The Raspberry Pi Pico's pins 14, 15, and 17 are used to connect the LED lights and buzzer. The system is run by a 5V and 2A power supply. All components connecting to pin numbers of Raspberry Pi Pico are enlisted in Table 2.

TABLE II
PIN NUMBERS CONNECTED WITH RASPBERRY PI PICO

Name of Component	*Component Pin Number*	*Raspberry Pi Pico Pin Number*
LCD display (16*2)	RS	GP2
	E	GP3
	D4	GP4
	D5	GP5
	D6	GP6
	D7	GP7
NodeMCU ESP8266	Vin	VBUS
	GND	GND
	GPIO5	GP8
	GPIO4	GP9
LED Red		GP14
LED Green		GP15
DHT11 - Temperature and Humidity Sensor	VCC	3V3(OUT)
	DATA	GP16
	GND	GND
Buzzer/ Alarm	VCC	GP17
	GND	GND
MQ4 - Methane Gas Sensor	VCC	3V3(OUT)
	GND	GND
	AO	GP26

By utilizing a variety of sensors and connectivity methods, an IoT-based fruit quality inspection and lifespan detection system could possibly be developed in order to monitor and assess the quality and freshness of fruits. The implemented model of the proposed system which detects the lifespan of fruit is given below:

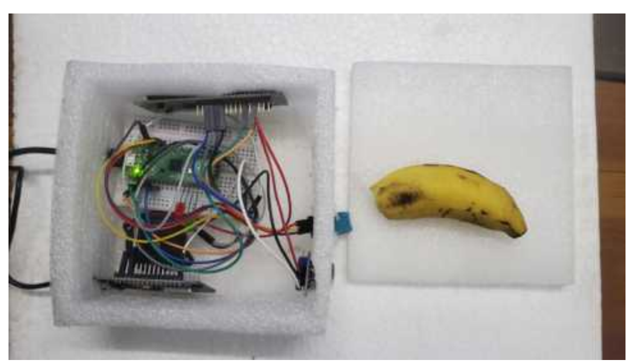

Fig. 5. Lifespan Detection of Banana Using Proposed System

VI. Result and Performance Analysis

The Raspberry Pi Pico connects the DHT-11 (temperature and humidity sensor) and MQ-4 (Methane gas sensor) to collect data from fruits and display it on the LCD display. Machine Learning (ML) algorithms/mathematical calculations are used to predict decay % and lifetime of fruits on basis of methane gas emission, temperature, and humidity data, resulting in the hazard level and remaining lifetime. As a result, a sample of predicted decay % and predicted lifetime is obtained, and from this lifetime, the hazard level and remaining lifetime are derived.

Table 3 represents the collected data on banana decay over time. A ripe banana can typically begin to show signs of decay within a few days when kept in a standard room temperature (20-25 degrees Celsius, or 68-77 degrees Fahrenheit) with moderate humidity.

TABLE III
Collected Data from Experiment (SQLite Database)

Timestamp	*Temperature*	*Humidity*	*Methane Level*
2023-03-24 00:12:09	24	78	870
2023-03-24 16:18:57	31	37	900
2023-03-24 21:55:18	24	70	1200
2023-03-25 00:14:49	22	75	1300
2023-03-25 00:41:09	23	74	1387
2023-03-25 01:40:25	22	71	1417
2023-03-25 03:45:25	21	71	1673
2023-03-25 05:25:53	21	71	1741
2023-03-25 06:35:53	20	72	1821
2023-03-25 08:05:53	22	73	1907
2023-03-25 10:05:53	24	75	1996

Figure 6 shows the emission of methane over time. As the fruit starts to decay, the emission of methane increases until it is fully decayed, and the emission becomes constant after the fruit has been fully decayed. From the graph, we can also observe that when the fruit starts to rot, it has a threshold of methane emission.

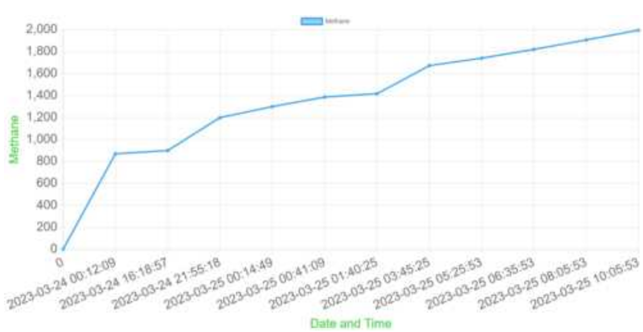

Fig. 6. MQ4 Methane Gas Sensor Based Collected Data Set Graph

Other gas sensors that can be used in a fruit quality inspection system, in addition to the Methane gas (CH_4) sensor, include Ethylene (C_2H_4) sensor, Carbon Dioxide (CO_2) sensor, Oxygen (O_2) sensor, Ammonia (NH_3) sensor, Volatile Organic Compound (VOC) sensor, Sulfur Dioxide (SO_2) sensor, and so on. To identify the quality and lifespan of any fruit, it is crucial to choose gas sensors according to the individual requirements and features of the fruit under inspection. Fruits may differ in their gas emission profiles and reactions to various gases, so it is important to select sensors appropriately. The gas sensors must be calibrated and validated to ensure accurate measurements and reliable fruit quality inspections. To maintain fruit quality throughout the supply chain, it's necessary to keep in mind that while an IoT-based system might offer useful insights, it should also be used alongside good agricultural methods, appropriate handling, and storage conditions.

VII. Conclusion and Future Research Directions

Food facilitates us with nutrients and other vital substances for repairing and growing tissues in our body. Moreover, various types of fruits and vegetables are enriched with a wide range of macro and micro nutrients with some specific nourishing properties, and these items grow in different seasons all over the year. Therefore, preservation of foods in cold storage or warehouses is essential for consuming food and satisfying future demands while preventing food spoilage. This paper solely focuses on food quality inspection by measuring humidity, temperature, and methane gas to determine the expiration date using the IoT (Internet of Things). Traditional machine learning methods for food freshness detection are quite lengthy and expensive as well. Therefore, implementation of IoT-based food freshness detection, including expiration dates, facilitates the avoidance of unnecessary health issues caused by the consumption of contaminated food items. Furthermore, the system has a higher accuracy rate for food spoilage and expiration date detection and is more cost-effective than other traditional machine learning techniques.

Our experiment is only done with bananas. Hence, for future projection, early decay detection of various fruit items, for instance, apples, oranges, kiwis, strawberries, and vegetables like tomatoes, potatoes, or other perishable vegetables, can also be implemented in cold storage or warehouses using the proposed system. Along with this, liquid food quality inspection and decay detection, such as in milk and fruit juices, can also be executed in the future to preserve their actual state. Based on possible future requirements, the proposed IoT-based food spoilage and expiration detection system can be employed in warehouses, supermarkets, and food item manufacturing industries. Besides these implementing sectors, this method can be utilized in our refrigerators for early detection of food spoilage in the near future. Conclusively, our experiment was conducted using the MQ-4 methane gas sensor and the DHT-11 temperature and humidity sensor. The project has some limitations too because the ethylene gas sensor and pH meter are absent from this research due to unavailability. With future development, the proposed system can be extended to determine the lifetime and expiration of other perishable items.

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