DESIGN AND IMPLEMENTATION OF ADVANCED PESTICIDE RESIDUE DETECTING TECHNIQUE FOR FRUITS AND VEGETABLES USING IOT AND ML BASED METHODS

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Abstract - The widespread use of pesticides in agriculture has led to concerns about pesticide residue in fruits and vegetables, posing serious health risks to consumers. Traditional methods of pesticide residue detection, such as gas chromatography and liquid chromatography, are slow, expensive, and laborious, making them unsuitable for rapid detection and widespread use. Biosensors offer a cost-effective alternative for screening pesticide residues in food matrices, but they lack the ability for remote control and information sharing.

To address these challenges, this paper proposes a novel approach using IoT (Internet of Things) and ML (Machine Learning) technologies for pesticide residue detection in fruits and vegetables. The integration of IoT sensors allows for real-time data collection from agricultural fields and post-harvest storage facilities. ML algorithms are employed for data analysis and prediction, enabling accurate and efficient detection of pesticide residues.

The necessity of pesticides in agriculture is emphasized due to the increasing population and demand for food, leading to adulteration and overuse of pesticides. The adverse impact of pesticides on human health, particularly organophosphate pesticides like chlorpyrifos, underscores the urgency for reliable detection methods. Various types of pesticides are discussed, highlighting the need for targeted detection methods. The problem statement emphasizes the critical challenge of pesticide contamination in the agricultural sector and the necessity for effective monitoring systems to ensure food safety.

The motivation behind the project is driven by concerns about public health, environmental impact, regulatory compliance, and consumer awareness. The paper provides an overview of embedded systems architecture and applications, emphasizing their relevance in addressing food safety concerns through real-time monitoring and detection of pesticide residues.

In conclusion, the proposed IoT and ML-based approach offers a promising solution for pesticide residue detection in fruits and vegetables, contributing to enhanced food safety, environmental sustainability, and consumer confidence in the food supply chain.
Keywords: Pesticide residue detection, Food safety, Biosensors, Gas chromatography, Liquid chromatography, Maximum residue levels (MRLs), Ethylene gas sensors, IR sensors, Chromogenic substrates, Chemometric-aided spectrofluorimetric method, Electronic nose, NDVI (Normalized Difference Vegetation Index), THz spectroscopy, D-SERS (Disposable Surface Enhanced Raman Spectroscopy).

1 INTRODUCTION

The widespread use of pesticides in agriculture has indeed revolutionized farming practices, leading to increased crop yields and ensuring food security for burgeoning populations. However, these benefits are accompanied by significant challenges, particularly concerning the presence of pesticide residues in fruits and vegetables. These residues, stemming from improper application practices and insufficient monitoring, pose potential health risks to consumers. Despite regulatory efforts to establish maximum residue levels (MRLs) for pesticides in food products, effectively monitoring and controlling pesticide contamination remains a formidable task.

Introduction to Pesticide Contamination in Agriculture: Pesticides stand as indispensable tools in modern agriculture, pivotal in bolstering farm productivity and ensuring food security amidst burgeoning populations. These chemical substances are instrumental in curbing agricultural pests and unwanted plant growth, ultimately leading to increased crop yields and a more sustainable food supply. However, the widespread application of pesticides has inadvertently resulted in the presence of pesticide residues in agricultural produce. This unintended consequence poses a significant concern for consumer safety, as prolonged exposure to these residues may have adverse health effects. Despite regulatory efforts to establish maximum residue levels (MRLs) for pesticides in food products, effectively monitoring and controlling pesticide contamination remains a formidable challenge, necessitating innovative approaches and technologies.

Traditional analytical techniques such as gas chromatography (GC) and liquid chromatography (LC) have long been the cornerstone of pesticide residue detection. While these methods offer high precision and sensitivity, they are often time-consuming, expensive, and labor-intensive. Moreover, they lack real-time capabilities and are not easily scalable, hindering their widespread adoption and effectiveness in monitoring pesticide contamination. As a result, there is a pressing need for alternative approaches that can provide rapid, cost-effective, and real-time detection of pesticide residues in agricultural produce.

Emerging technologies, such as biosensors and wireless sensor networks, offer promising solutions to the challenges posed by pesticide contamination in agriculture. Biosensors, leveraging biological components, provide a rapid and sensitive means of detecting pesticide residues in food matrices. Additionally, advancements in wireless sensor technologies have facilitated the development of the Internet of Things (IoT), enabling seamless communication and data sharing among interconnected devices. By harnessing these technologies, a novel approach to pesticide residue detection can be realized, offering real-time monitoring capabilities and enhancing traceability throughout the agricultural supply chain.

Challenges in Traditional Analytical Techniques: Traditional methods such as gas chromatography (GC) and liquid chromatography (LC) have long been indispensable for detecting pesticide residues in agricultural produce. These techniques offer high precision and sensitivity, enabling accurate identification and quantification of pesticide contaminants. However, despite their effectiveness, they suffer from several drawbacks that limit their utility in real-world applications. For instance, GC and LC methods are notorious for being time-consuming and labor-intensive, requiring extensive sample preparation and analysis procedures. Additionally, the equipment and expertise needed to perform these analyses can be prohibitively expensive, making them inaccessible to many agricultural stakeholders. Furthermore, these traditional methods lack real-time monitoring capabilities, meaning that results are not immediately available, delaying decision-making processes and potentially compromising food safety.

Moreover, the scalability and data-sharing capabilities of GC and LC methods are limited, further impeding their widespread adoption. Due to their resource-intensive nature, these techniques are often confined to specialized laboratory settings, restricting their use to specific locations and personnel. Additionally, the data generated from GC and LC analyses are typically stored locally and may not be readily accessible for sharing or collaboration purposes. This lack of data sharing hampers efforts to develop comprehensive pesticide monitoring programs and inhibits the timely dissemination of information to relevant stakeholders. As a result, there is a growing need for alternative approaches that can overcome these limitations and provide more efficient and accessible solutions for pesticide residue detection in agriculture.

Emerging Technologies for Pesticide Residue Detection: The emergence of biosensors, incorporating biological elements, represents a significant advancement in the detection of pesticide residues. These innovative devices offer rapid and cost-effective solutions for identifying contaminants in agricultural produce. By harnessing biological components, biosensors can detect pesticides with high sensitivity and specificity, providing accurate results in a fraction of the time required by traditional methods. Furthermore, the integration of wireless and sensor technologies has ushered in the era of the Internet of Things (IoT), enabling seamless connectivity and data exchange among interconnected devices. This interconnected network of sensors and devices can be leveraged to create a comprehensive monitoring system for pesticide residues in real-time, facilitating timely intervention and ensuring the traceability of agricultural products throughout the supply chain.

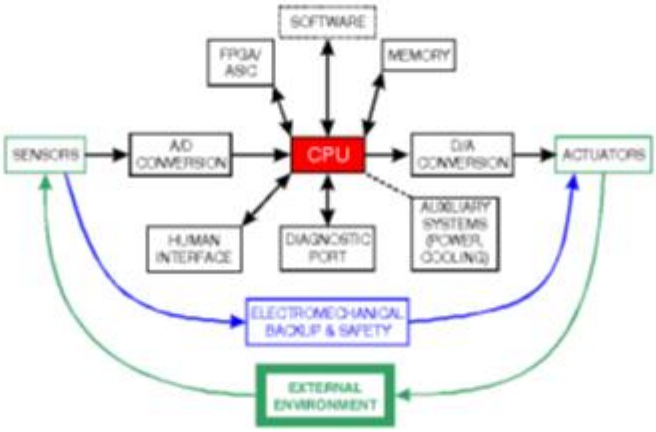

Figure 1 Overview diagram of Embedded system

Motivation for Addressing Pesticide Contamination: Addressing pesticide contamination in agriculture is driven by a multitude of factors, all of which underscore the importance of ensuring food safety and integrity. One of the primary motivations stems from concerns about public health. Pesticide residues present in fruits and vegetables can pose significant risks to consumers if consumed in excessive amounts, leading to acute or chronic health issues. Moreover, there are growing apprehensions about the environmental sustainability of agricultural practices. The indiscriminate use of pesticides can have detrimental effects on ecosystems, including soil degradation, water pollution, and harm to non-target organisms.

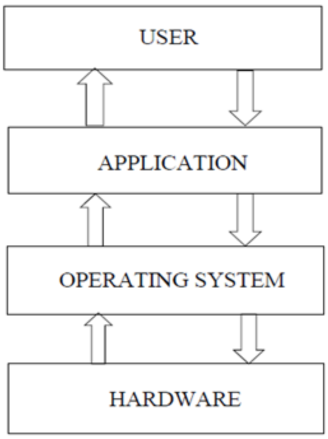

Figure 2 Embedded Block diagram

Additionally, regulatory compliance plays a crucial role in motivating efforts to mitigate pesticide contamination. Regulatory agencies worldwide enforce stringent guidelines and maximum residue limits (MRLs) for pesticides in food products to protect consumer health and safety. Failure to comply with these regulations can result in legal consequences and damage to the reputation of food producers and suppliers. Moreover, consumer trust in agricultural products is closely tied to their perception of safety and quality. Transparency and accountability in the food supply chain are essential for maintaining consumer confidence and ensuring long-term sustainability.

2 LITERATURE REVIEW

Aradhana B S and Aishwarya Raj [1] proposed a methodology for detecting pesticide residue in fruits and vegetables using three integrated modules. The first module utilizes a CNN-based framework for fruit recognition based on size, color, and texture. The second module incorporates IR and ethylene gas sensors to detect sample quality and ripeness, respectively. The third module utilizes an LDR sensor for pesticide residue detection using the NDVI method. If the obtained values exceed the threshold, the system displays "REJECT" on the LCD, indicating pesticide presence.

Shengan Wang and Taota Mu [2] proposed a system for detecting pesticides using a nano SERS (Surface Enhanced Raman Spectroscopy) chip integrated with a smartphone-based Raman sensor. The system consists of an SERS chip, adaptor, and SERS terminal. It detects various pesticide molecules by collecting Raman signals after applying a diluted sample to the SERS chip. The measurements are processed using a mobile application.
Hyeok Jung Kim and Yeji Kim [3] developed a system for pesticide detection using colorimetry. They utilized a paper microfluidic device with hydrophobic barriers to probe organophosphate pesticides. The system employs lateral flow assay (LFA) technology and chromogenic substrates to detect pesticide inhibition of acetyl cholinesterase, resulting in color changes that indicate pesticide presence.

M Villar Navarro and Miguel A Cabezon [4] proposed a chemometric-aided spectrofluorimetric method for concurrent determination of fluorescent pesticides in fruits. Their system combines second-order fluorescence data with unfolded partial least squares and residual bilinearization to overcome spectral interferences. The method enables the detection of pesticides in fruits with high sensitivity and accuracy.

Fabio Leccese and Cagnetti Sabino [5] introduced an electronic nose system for pesticide detection using parallel commercial gas sensors. The system utilizes dynamic sensors and Lab VIEW software for data analysis. Different sensor responses to various gases are analyzed to discriminate and locate pesticides.

Deepali Gupta and Balwinder Singh Lakha [6] proposed a system for pesticide detection in vegetable samples using sensors measuring electrical conductivity and pH. Their method involves preparing solutions from vegetable extracts and evaluating pesticide presence based on sensor readings. A graphical comparison of results determines the presence of pesticide residues.

Tejkanwar Singh and Mandeep Singh [7] developed a handheld device for pesticide detection using NDVI. Their system employs IR sensors, a photodiode, and microcontroller circuits to calculate NDVI values for organic and inorganic subjects. A comparison of NDVI values indicates pesticide levels in the sample.

Dong-kyu Lee and Giyoung Kim [8] utilized THz near-field enhancement for ultrasensitive pesticide detection. Their system employs nanoscale metamaterials and THz spectroscopy to detect pesticide residues on fruit surfaces. The method provides clear imaging of pesticide-stained spots, enabling effective detection.

Huang Xingjiu and Lui Jinhauai [9] proposed a system for pesticide detection based on the appearance of pesticide gases using a SnO_2 sensor. The system quantitatively analyzes binary gas mixtures using temperature modulation and gas sensitivity measurements, enabling the detection of pesticide gases in air.

Yiqun Zhu and Liangbao Yang [10] developed a system for pesticide residue detection on fruit peels using D-SERS. Their method employs Ag NP-decorated filter paper combined with D-SERS for precise and efficient detection and identification of pesticide residues on fruit surfaces.

Dr. Bhandri Ranu [11] developed a method for pesticide detection in vegetables and fruits using the QuEChERS method. Their system involves sample preparation, extraction, and gas chromatography analysis to detect and quantify pesticide residues in fruits and vegetables.

Guo Zhaol and Yemin Guol [12] proposed a system for pesticide detection based on the Internet of Things (IoT) and an acetylcholinesterase biosensor. Their system consists of a biosensor-based computer and a Lab VIEW-based information exchange platform for wireless data transmission and database access.

Rohan Dasika and Siddharth Tangirala [13] developed a method for screening pesticide residues in fruit and vegetable samples using liquid chromatography tandem mass spectrometry (LC-MS/MS). Their method involves QuEChERS sample preparation followed by LC-MS/MS analysis to detect and quantify pesticide residues in fruit and vegetable samples.

3 PROBLEM STATEMENT

The agricultural sector confronts a pressing issue: the extensive use of pesticides and the ensuing risks posed by pesticide residues in fruits and vegetables. This situation not only jeopardizes human health but also poses significant threats to the environment. Consequently, there is an urgent need for the development of effective monitoring systems to ensure food safety by addressing the shortcomings of existing methods, which often lack real-time capabilities and fail to provide comprehensive insights into the dynamic nature of pesticide levels.

4 EXISTING MODEL

In the existing system for disease detection, a three-stage process utilizing edge-based processing is employed for image segmentation. The initial stage involves converting the RGB image to grayscale, followed by median filtering, edge detection, and morphological operations. Subsequently, in the second stage, features from both domains are compared for extraction, and in the third stage, images are separated using a separate kernel on a vector support machine. Classification is achieved by applying neural networks, which are trained with a comprehensive database. Disease detection relies on comparing each label with the database, and if a match is found, the disease is identified.

The existing system for disease detection presents several drawbacks that hinder its overall effectiveness and usability. Firstly, the system's complexity makes it challenging to design and implement. Its intricate nature requires specialized knowledge and expertise, posing barriers to entry for individuals or organizations seeking to adopt or adapt the system. Moreover, the high cost associated with the system is a significant limitation. The equipment and resources required for its operation result in substantial financial investments, rendering it less accessible, particularly for farmers with limited financial resources. The complexity of the system also contributes to challenges in maintenance and operation. Its intricate design may necessitate ongoing technical support and troubleshooting, increasing the burden on users and potentially leading to downtime or disruptions in service. One of the most significant drawbacks of the existing system is the potential for financial losses for farmers. If the system fails to accurately detect diseases or pests in crops, farmers may experience reduced yields or compromised produce quality, resulting in significant economic losses.

Additionally, the system may exhibit suboptimal performance in terms of accuracy and efficiency. Variability in detection capabilities or errors in analysis could undermine the reliability of the system, impacting its overall effectiveness in disease management. Furthermore, the lack of integration with Internet of Things (IoT) technology limits the system's connectivity and real-time monitoring capabilities. Without IoT integration, users may have limited visibility into crop health and environmental conditions, hindering proactive decision-making and timely interventions. Overall, addressing these drawbacks is essential for improving the functionality, accessibility, and effectiveness of disease detection systems in agriculture.

5 PROPOSED METHODOLOGY

The proposed system represents a pioneering solution for detecting pesticide residues on fruits and vegetables through the integration of IoT and machine learning technologies. By amalgamating a diverse array of sensors such as pH, gas, and an ESP32 camera, alongside NodeMCU and the Ubidots platform, this system enables comprehensive data collection and analysis. Through the utilization of these sensors, coupled with image capture capabilities, the system gathers valuable information regarding the quality and composition of agricultural produce.

Following data acquisition, the captured images undergo a series of preprocessing, segmentation, and feature extraction steps to isolate pertinent information. Subsequently, both the sensor data and extracted features are fed into a pre-trained machine learning model. This model, built upon a foundation of extensive training data, facilitates the classification of fruit or vegetable types and the identification of pesticide residues. The system's ability to provide real-time, cost-effective, and non-destructive detection further underscores its potential to significantly enhance food safety and quality assurance measures.

The hardware architecture of the proposed system revolves around the ESP8266 microcontroller, which functions as the central processing unit. This microcontroller seamlessly connects to an array of sensors and devices crucial for data collection and analysis. Upon establishing a connection with the server device, the gathered sensor data undergoes swift transmission to a designated web server. Subsequently, this processed sensor data finds its place in a cloud-based database facilitated by a Wi-Fi module like Node-MCU. Among the sensors integrated into the system, gas sensors such as the MQ135 play a pivotal role in detecting gases present in fruits and vegetables, offering valuable insights into their quality. Complementing this, temperature and humidity sensors contribute to assessing the health of fruits by monitoring their temperature and identifying any abnormal heat levels, indicative of potential disease or decay.

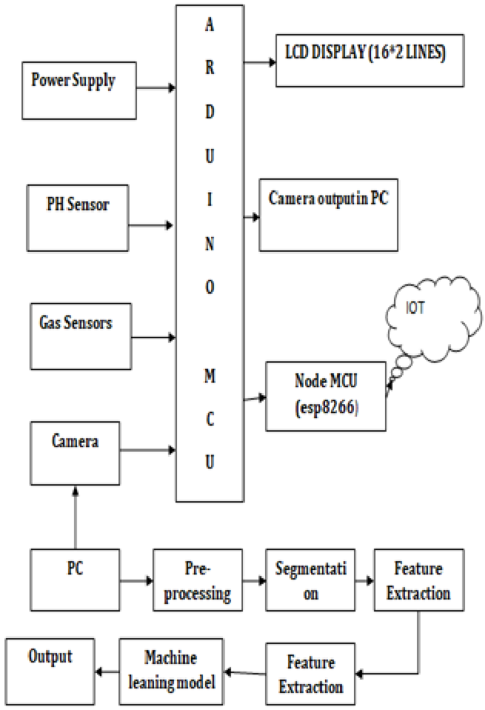

Figure 3 Proposed Architecture

The proposed hardware setup thus forms a robust foundation for the system's functionality, facilitating efficient data acquisition and analysis while enabling real-time monitoring of agricultural produce quality. The software aspect of the proposed system is centered around sophisticated image processing techniques aimed at disease identification through machine learning. Initially, the system captures digital images of fruits using a camera, compiling a dataset of 50 different types of images specifically for training purposes. Through a series of image processing stages, including restoration, segmentation, and enhancement, the system extracts crucial features such as color values and pixel data. Notably, image segmentation techniques like k-means clustering are employed to divide the images into distinct subgroups, facilitating focused analysis.

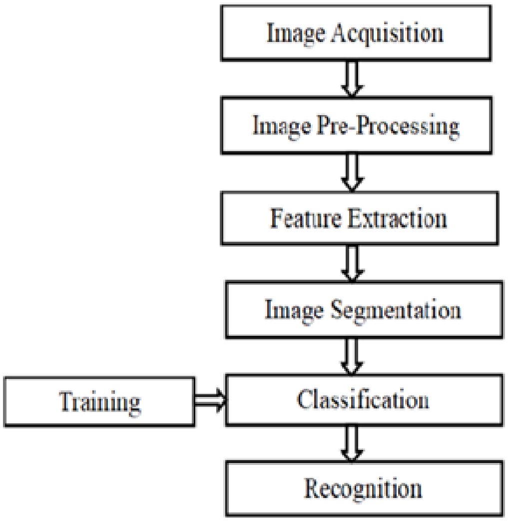

Figure 4 Design Procedure

Following segmentation, the extracted features undergo comparison with a stored dataset to identify potential diseases affecting the fruits. This comparison process leverages machine learning algorithms for predictive analysis, enabling the system to recognize patterns indicative of various diseases. By harnessing the power of machine learning, the proposed system can accurately classify fruit images and detect any anomalies associated with pesticide residues

In conclusion, the proposed system offers a comprehensive solution for pesticide residue detection in fruits and vegetables. By seamlessly integrating hardware and software components, it enables efficient, real-time monitoring and analysis of agricultural produce, thereby enhancing food safety and quality assurance measures.

6 RESULTS

The proposed system represents a pioneering solution for detecting pesticide residues on fruits and vegetables through the integration of IoT and machine learning technologies. By amalgamating a diverse array of sensors such as pH, gas, and an ESP32 camera, alongside NodeMCU and the Ubidots platform, this system enables comprehensive data collection and analysis. Through the utilization of these sensors, coupled with image capture capabilities, the system gathers valuable information regarding the quality and composition of agricultural produce. Following data acquisition, the captured images undergo a series of preprocessing, segmentation, and feature extraction steps to isolate pertinent information. Subsequently, both the sensor data and extracted features are fed into a pre-trained machine learning model. This model, built upon a foundation of extensive training data, facilitates the classification of fruit or vegetable types and the identification of pesticide residues. The system's ability to provide real-time, cost-effective, and non-destructive detection further underscores its potential to significantly enhance food safety and quality assurance measures.

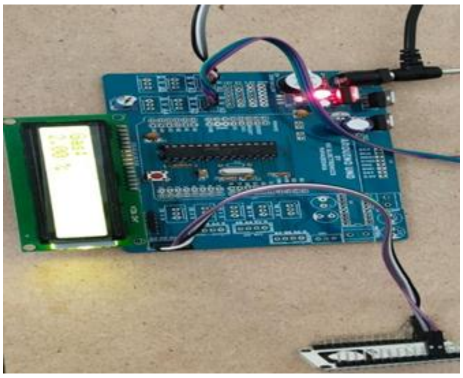

Figure 5 Showing detected gas level

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Figure 5 Graphical Analysis in UBIDOTS

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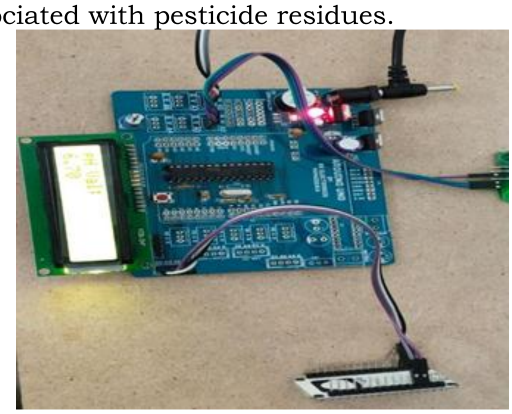

Figure 6 Showing detected Ph value

In conclusion, the proposed system offers a comprehensive solution for pesticide residue detection in fruits and vegetables. By seamlessly integrating hardware and software components, it enables efficient, real-time monitoring and analysis of agricultural produce, thereby enhancing food safety and quality assurance measures.

Furthermore, the precise and reliable detection capabilities of our system contribute to enhancing consumer confidence in the food supply chain. By providing accurate information about pesticide residues in fruits and vegetables, consumers can make informed decisions about their food choices, thereby promoting healthier eating habits and overall well-being. The wireless connectivity and cost-effectiveness of our system ensure its accessibility to various stakeholders, including farmers, food processors, retailers, regulatory authorities, and consumers. This accessibility fosters widespread adoption and facilitates proactive monitoring throughout the food supply chain. Moreover, the proactive monitoring capabilities of our system enable timely intervention in the event of pesticide contamination, thereby promoting compliance with regulatory standards and contributing to a safer and more sustainable food supply chain.

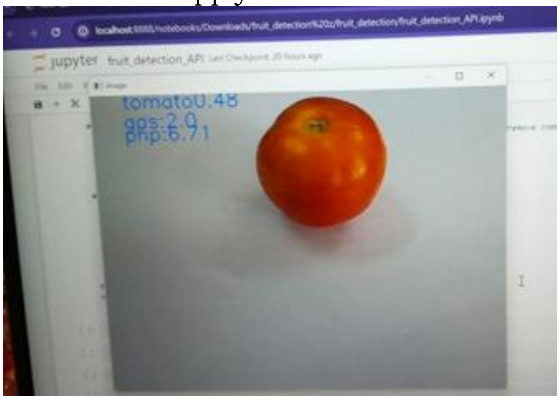

Figure 7 Showing results for Tomato

Overall, our project represents a significant advancement in pesticide monitoring technology, addressing critical concerns in the agricultural sector and supporting efforts towards safer and healthier food production practices. Through continued research and innovation, we aim to further refine and optimize our system, ultimately contributing to the improvement of food safety standards worldwide.

7 CONCLUSION

In conclusion, our project provides a robust and comprehensive solution for real-time monitoring of pesticide levels in fruits and vegetables. Through the integration of Arduino-based hardware and machine learning algorithms, we have developed a system capable of accurately detecting pesticide contamination using sensors for pH, gas detection, and visual inspection. By offering precise and reliable detection capabilities, our system significantly enhances food safety and consumer confidence in agricultural produce.

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8 FUTURE SCOPE

In the future, advancements in sensor technologies hold promise for revolutionizing pesticide residue detection. Innovations in nanotechnology, bioelectronics, and material science are expected to lead to the development of sensors that are more sensitive, selective, and cost-effective. These sensors will enable more accurate and reliable detection of pesticide residues in fruits and vegetables, contributing to improved food safety standards. Moreover, the miniaturization and integration of sensor devices are anticipated to play a crucial role in enhancing pesticide residue detection systems. Compact and portable devices will facilitate on-site testing in agricultural fields and post-harvest facilities, enabling real-time monitoring and timely interventions to mitigate pesticide contamination risks.

Further integration of Internet of Things (IoT) technologies is poised to enhance the capabilities of pesticide residue detection systems. IoT-enabled devices can provide continuous monitoring of environmental parameters, crop health, and pest infestations, enabling farmers to implement proactive pest management strategies and optimize pesticide usage. Automation and robotics are also expected to streamline pesticide residue detection processes, reducing human intervention and potential errors. Autonomous robotic systems equipped with sensors and artificial intelligence algorithms will be able to navigate agricultural fields, collect samples, and perform detection tasks with high accuracy and efficiency.

Advancements in data analytics and artificial intelligence will continue to improve the accuracy and efficiency of pesticide residue detection systems. Machine learning algorithms will analyze large datasets to identify patterns and trends, enabling more reliable detection and prediction of pesticide contamination. Integration of blockchain technology can enhance traceability and transparency in the agricultural supply chain, ensuring the authenticity and compliance of agricultural products with regulatory standards. Blockchain-based systems will securely record and track the entire journey of agricultural products from farm to fork, providing consumers with assurance regarding the safety and quality of their food.

Collaborative research efforts involving multidisciplinary teams will drive innovation in pesticide residue detection technologies. By bringing together experts from fields such as agriculture, chemistry, engineering, and data science, holistic solutions can be developed to address the complex challenges associated with pesticide contamination. Continuous dialogue between researchers, industry stakeholders, and regulatory agencies will be essential for establishing standardized protocols and guidelines for pesticide residue detection. Adherence to international standards will ensure the reliability, accuracy, and interoperability of detection methods across different regions and markets.

Education and awareness programs aimed at farmers, food processors, consumers, and policymakers will promote responsible pesticide use and food safety practices. Training initiatives on proper pesticide application techniques, alternative pest management strategies, and understanding pesticide labeling will contribute to reducing pesticide residues in agricultural products. Emphasis on environmentally sustainable agricultural practices, such as integrated pest management (IPM) strategies, organic farming practices, and agroecological approaches, will minimize the use of pesticides and reduce their impact on ecosystems. These initiatives will promote natural pest control mechanisms and preserve biodiversity, ensuring a more sustainable and resilient food supply chain for future generations.

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