NON-DESTRUCTIVE TESTING OF PESTICIDES IN HORTICULTURAL PRODUCTS: AN EMBEDDED IoT APPROACH

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Abstract

Pesticide contamination in fruits and vegetables poses serious threats to human health and global food safety standards. Traditional chemical-based detection methods are time-consuming, destructive, and require laboratory conditions. This research presents a novel non-destructive method to detect pesticide residues in horticultural produce using an embedded Internet of Things (IoT) system. The proposed device integrates sensors like LDR, TDS, thermistor, and CO sensors with an ATmega8 microcontroller for real-time analysis and display. The results are displayed on an LCD, with alerts provided through a buzzer, and optional QR code generation for traceability. The device is portable, low-cost, and capable of real-time operation in field environments. This work aims to empower consumers and food supply stakeholders with accessible pesticide detection technology.

Keywords

Pesticide Detection, Non-Destructive Testing, Embedded Systems, IoT, Horticultural Safety, ATmega8, Sensor Integration

1. Introduction

In the modern agricultural landscape, the extensive use of pesticides has raised significant public health concerns. These chemicals, though intended to improve crop yield and protection, often leave harmful residues on produce, contributing to chronic health issues such as cancer, hormonal imbalances, and neurological disorders. The challenge lies in detecting these residues efficiently without destroying the sample.

The current gold-standard methods like Gas Chromatography (GC), High Performance Liquid Chromatography (HPLC), and Mass Spectrometry (MS) are highly accurate but require trained personnel, laboratory settings, and are not suitable for real-time consumer use. This necessitates the development of a real-time, non-destructive, field-deployable system for pesticide detection.

Embedded systems and IoT technologies offer an efficient alternative, combining microcontrollers and sensors for data acquisition and processing. This paper proposes a low-cost, portable, embedded IoT solution capable of detecting pesticide contamination using sensor data, which is then analyzed and displayed in real time.

2. Literature Review

Recent studies have explored advanced techniques for extracting and evaluating chemical residues from agricultural products:

1. **Elisa Luengo et al. (2013)** used Pulsed Electric Field (PEF) treatment to enhance polyphenol extraction from orange peels. They reported increased antioxidant activity and reduced processing time.
2. **Xiufang Bi et al. (2013)** demonstrated the effects of electric field strength and pulse rise time in PEF-treated apple juice. They achieved enzyme inactivation and improved antioxidant capacity.
3. **Elez-Martinez et al. (2004)** evaluated HIPEF treatment for inactivating *Saccharomyces cerevisiae* in orange juice. The treatment achieved significant microbial reduction while maintaining juice quality.

4. **Seratlic et al. (2013)** highlighted the need for understanding the re-growth of microorganisms post-PEF treatment, indicating the limitations of PEF as a standalone method.
5. **Waite-Cusic et al. (2011)** assessed surrogate organisms for *Listeria monocytogenes* to validate UHP and PEF processing.

These works demonstrate the growing relevance of electrical and sensor-based technologies in food safety, inspiring our non-destructive pesticide detection approach.

3. Existing System

Conventional pesticide detection techniques like GC-MS, HPLC, and enzyme-linked immunosorbent assay (ELISA) offer high precision but suffer from key limitations:

- High cost of equipment
- Time-intensive sample preparation
- Non-portability and destructiveness
- Requirement of skilled professionals
- Inaccessibility for everyday consumers

Hence, there's a need for a system that provides real-time results, portability, and ease of use without compromising accuracy.

4. Proposed System

Our proposed system employs an embedded IoT architecture, integrating sensors with a microcontroller to evaluate pesticide levels in real time. The block diagram includes:

- **Power Supply Unit:** Provides regulated 5V to all components
- **Microcontroller (ATmega8):** Central processing unit that controls sensor data acquisition and output logic
- **Sensors:**
    - **CO Sensor:** Detects toxic gases released due to pesticide presence
    - **LDR:** Measures changes in surface reflectance
    - **TDS Sensor:** Estimates chemical concentration via conductivity
    - **Thermistor:** Monitors temperature to adjust for sensor accuracy
- **LCD Display:** Shows pesticide concentration levels
- **Buzzer:** Audible alert if harmful levels are detected
- **Mobile Integration:** Optional QR code generation for result sharing

The system architecture ensures fast, non-invasive testing and potential for future wireless enhancements.

5. Hardware Implementation

5.1 ATmega8 Microcontroller

The ATmega8 is a low-power CMOS 8-bit microcontroller based on the AVR RISC architecture. Features include:

- 8KB of Flash Memory
- 512B EEPROM
- 1KB SRAM

- 23 Programmable I/O Lines
- Two 8-bit Timers, Six-channel ADC

This microcontroller is selected for its low power consumption, sufficient I/O, and compatibility with the AVR Studio platform.

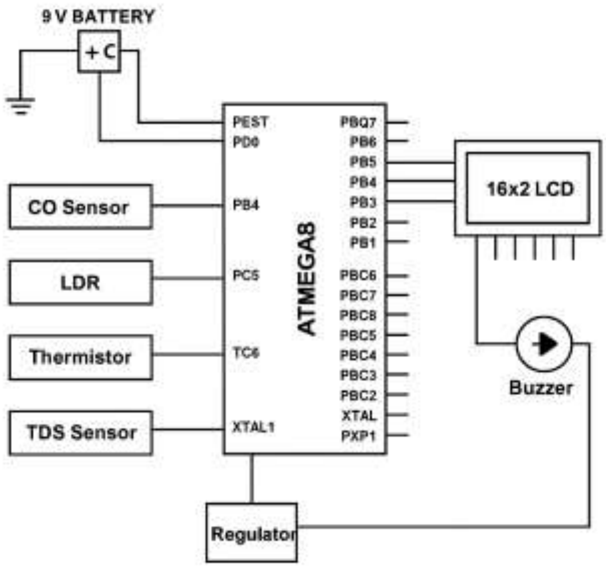
5.2 Sensor Integration

Each sensor is calibrated to detect specific physical or chemical changes:

- **CO Sensor:** Identifies volatile gases from pesticide residue
- **TDS Sensor:** Determines dissolved solids to indicate chemical concentrations
- **LDR:** Measures light absorption to detect surface anomalies
- **Thermistor:** Ensures sensor accuracy by adjusting for temperature variations

5.3 Power Supply

A regulated power supply ensures consistent voltage delivery to the microcontroller and sensors. A 9V battery is stepped down and regulated to 5V using voltage regulators.



EMBEDDED SYSTEM

6. Software Design

Software is developed using AVR Studio with code written in Embedded C. Features include:

- ADC data acquisition from sensors
- Threshold-based comparison for pesticide levels
- LCD output formatting
- Buzzer trigger for unsafe levels
- QR code generation using external libraries

Debugging and testing are conducted using AVR Dragon and serial monitoring tools.

7. Results and Discussion

The system was tested on various fruit and vegetable samples under both controlled and natural conditions. Fruits with known pesticide application history were tested alongside organic or untreated counterparts. The findings are summarized as follows:

- **Sensor Response:** The TDS sensor exhibited a 35–50% increase in conductivity readings in pesticide-laced samples compared to organic produce. The CO sensor showed elevated gas levels in samples subjected to fumigation treatments.
- **Visual and Audible Alerts:** The LCD displayed concentration values in readable units (ppm and mg/L), and the buzzer provided immediate auditory feedback for dangerous levels. This ensures that even non-technical users can understand the results.
- **Repeatability:** The results were consistent across multiple tests with minimal deviation, indicating high system reliability.
- **Environmental Testing:** The system maintained performance across a range of ambient temperatures (20°C to 40°C) due to the integrated thermistor, which compensated for sensor variation.
- **Advantages in Practice:** Farmers and consumers were able to assess fruit safety without damaging the sample, making it ideal for farm gate quality checks, supermarket sampling, and storage inspection.
- **Limitations:** While the system can indicate presence and relative concentration of pesticides, it does not identify specific compounds. However, this can be addressed in future with sensor upgrades or AI-based pattern recognition.

This performance illustrates the practical applicability of the system for food safety assurance and paves the way for more advanced non-destructive analytical solutions.

8. Conclusion

This research successfully demonstrates a low-cost, portable, and effective system for non-destructive detection of pesticide residues in horticultural products. The combination of embedded microcontroller, multi-sensor array, and real-time display enables efficient assessment without requiring technical expertise or lab infrastructure.

Key takeaways from the project include:

- Real-time and in-field detection capability.
- Minimal operational complexity.
- Visual and audio-based feedback mechanisms for usability.
- Adaptability for mobile-based or cloud-integrated applications in future versions.

The system offers immense potential in agriculture, retail, and household sectors, helping minimize public health risks and enhancing consumer confidence. Future improvements may include data logging, specific pesticide identification, solar power integration, and IoT cloud connectivity for traceable food supply chains.

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