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COLD PLASMA CONVEYOR SYSTEM WITH LEAK DETECTION

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Abstract: Food safety and quality assurance are major concerns in modern food processing and packaging industries. Conventional inspection systems mainly rely on manual monitoring, which may lead to inconsistent detection of defective packages and increased operational costs. This project presents the design and development of a Cold Plasma Conveyor System with Leak Detection using Python-based image processing for automated inspection and sterilization of packed food products. In the proposed system, a conveyor mechanism driven by a DC motor transports the packaged products through different processing stages. A USB camera captures real-time images of the packages, which are analyzed using Python image processing algorithms to detect defects such as packet leakage, cracks, or improper sealing. If a defective package is identified, a servo motor-based rejection mechanism automatically removes it from the conveyor line. The accepted products then move to the cold plasma treatment zone, where non-thermal plasma is applied to sterilize the package surface and eliminate microorganisms without affecting food quality. The system improves inspection accuracy, reduces human intervention, and enhances hygiene standards in automated food processing environments

Keywords: Cold Plasma Sterilization, Conveyor Automation, Image Processing, Leak Detection, Python-Based Inspection, Food Packaging Safety, Servo-Based Rejection System, Automated Quality Control.

I. INTRODUCTION

Food safety and quality assurance have become critical concerns in modern food processing and packaging industries due to the increasing demand for hygienic packaged food products. Packaging defects such as leakage, cracks, and improper sealing can lead to microbial contamination and reduced product shelf life. Traditional inspection methods rely on manual visual monitoring, which is often slow, inconsistent, and prone to human errors. Therefore, automated inspection systems are required to ensure reliable defect detection and maintain product quality standards.

Recent advancements in machine vision and image processing technologies have enabled automated defect detection in food packaging systems. Computer vision algorithms can analyze product images in real time and identify packaging defects with higher accuracy and efficiency compared to manual inspection [1], [2]. Deep learning techniques such as convolutional neural networks have further improved defect detection accuracy by recognizing complex patterns and anomalies in packaging materials [3], [4]. These technologies are increasingly used in industrial inspection systems to improve quality control and production efficiency [5], [6].

Another important aspect of food safety is sterilization. Conventional thermal sterilization methods can negatively affect food quality and packaging integrity. To overcome these limitations, researchers have explored non-thermal sterilization techniques such as cold plasma technology, which has shown promising results in food processing applications [8], [9]. Cold plasma generates reactive oxygen and nitrogen species capable of destroying microorganisms on food surfaces without increasing product temperature [10], [11].

Recent studies have reported that cold plasma treatment can effectively reduce microbial contamination and improve food preservation while maintaining product quality [12], [13]. Additionally, cold plasma technology has been successfully applied in food packaging systems to enhance safety and extend shelf life [14], [15]. Due to its energy efficiency and environmentally friendly characteristics, cold plasma is considered a promising technology for modern food processing industries [16].

In addition to sterilization, artificial intelligence and machine vision technologies have been widely adopted for automated quality inspection systems. AI-based inspection systems can analyze images and detect product defects with high accuracy in industrial production environments [17], [18]. Deep learning models have also been used to detect food defects and improve automated quality monitoring systems [19], [20].

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Therefore, this study proposes a Cold Plasma Conveyor System with Leak Detection using Python-based Image Processing to improve packaging inspection accuracy and ensure effective sterilization of packaged food products.

1.1 Background of the Problem

In recent years, the demand for packaged food products has increased significantly due to urbanization and modern lifestyles. However, packaging defects such as leakage, cracks, and improper sealing can lead to contamination and reduced shelf life of food products. In many food processing industries, inspection of packaged products is still performed manually, which is often inefficient and prone to human error. Therefore, reliable and automated inspection systems are required to ensure product quality and safety.

1.2 Importance of Food Safety

Food safety is a critical factor in the food processing and packaging industry. Contaminated or damaged packaged food products can cause serious health risks to consumers and result in economic losses for manufacturers. Maintaining proper hygiene and eliminating microorganisms during packaging is essential to improve product shelf life and meet international food safety standards.

1.3 Need for Automation and Inspection

Manual inspection systems are time-consuming and cannot efficiently detect small defects in high-speed production lines. Automated inspection systems using machine vision and image processing technologies provide accurate and real-time defect detection. These systems help industries improve inspection accuracy, reduce labor costs, and maintain consistent product quality.

1.4 Overview of Cold Plasma Technology

Cold plasma technology has emerged as an effective non-thermal sterilization technique for food processing applications. Cold plasma generates reactive oxygen and nitrogen species capable of destroying microorganisms without increasing the temperature of the food product. This makes it suitable for sterilizing heat-sensitive packaged foods while preserving their nutritional quality and packaging integrity.

1.5 Paper Contribution

This paper proposes a Cold Plasma Conveyor System with Leak Detection using Python-based Image Processing. The system integrates machine vision-based defect detection with a conveyor-driven automated rejection mechanism and cold plasma sterilization unit. The proposed approach improves inspection accuracy, reduces human intervention, and enhances food safety in automated packaging industries.

II. LITERATURE REVIEW

Several researchers have investigated automated inspection systems for food packaging and processing industries. Machine vision systems have been widely used for defect detection because they provide higher accuracy and faster inspection compared to manual methods [1], [2]. Edge detection and image processing techniques have been applied to identify packaging defects such as cracks, leakage, and surface irregularities in real-time inspection systems [3].

Recent advancements in artificial intelligence have further improved defect detection performance. Deep learning algorithms such as convolutional neural networks have been successfully applied for automated packaging inspection and food defect detection [4], [5]. Spectral imaging and machine learning techniques have also been used to classify defects in agricultural and food products with high accuracy [6], [7].

Cold plasma technology has gained significant attention as a non-thermal sterilization technique for food processing applications. Researchers have demonstrated that cold plasma treatment can effectively eliminate microorganisms on food surfaces without affecting food quality [8], [9]. The reactive species generated by cold plasma can destroy bacteria, fungi, and other pathogens present on food packaging materials [10], [11].

Several studies have also reported the effectiveness of cold plasma in improving food preservation and extending shelf life by reducing microbial contamination [12], [13]. In addition, cold plasma has been applied to food packaging systems to enhance packaging safety and improve hygienic processing conditions [14], [15]. Due to its environmental benefits and energy efficiency, cold plasma technology is considered a promising solution for modern food safety applications [16].

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Recent research has also explored the integration of artificial intelligence and machine vision technologies in food quality inspection systems. AI-based inspection systems can automatically detect product defects and improve industrial production efficiency [17], [18]. Deep learning techniques have further enhanced defect detection accuracy in food processing and packaging industries [19], [20].

However, most existing studies focus on either automated inspection or cold plasma sterilization individually. Very few systems integrate defect detection and sterilization in a single automated platform. Therefore, the proposed system combines Python-based image processing with a conveyor-based cold plasma sterilization system to improve food safety and packaging quality.

III. PROBLEM STATEMENT

3.1 Issues with Current Manual Inspection

In many food packaging industries, the inspection of packaged products is primarily carried out through manual visual monitoring by operators. This method is time-consuming and highly dependent on human judgment. Due to fatigue, limited observation capability, and high production speeds, operators may fail to detect small defects such as packet leakage, cracks, or improper sealing. As a result, defective products may pass through the inspection stage and reach the market, leading to food contamination, reduced product shelf life, and potential health risks for consumers. Additionally, manual inspection increases labor costs and reduces production efficiency in large-scale manufacturing environments.

3.2 Need for Automated Inspection and Sterilization

To overcome these limitations, automated inspection systems are required to ensure consistent and reliable quality control. Machine vision and image processing technologies can detect packaging defects in real time with higher accuracy and speed compared to manual inspection. Furthermore, traditional sterilization methods often involve thermal or chemical processes that may damage packaging materials or affect food quality. Therefore, integrating automated inspection with non-thermal sterilization technologies such as cold plasma can improve food safety, maintain product quality, and enhance industrial productivity. The development of an automated system capable of detecting defective products and performing efficient sterilization is essential for modern food processing industries.

IV. PROPOSED SYSTEM

The proposed system integrates automated inspection, defect rejection, and non-thermal sterilization for packaged food products. A conveyor mechanism transports products through different processing stages including image inspection, defect detection, rejection, and cold plasma sterilization. A USB camera captures real-time images of the packaged products, which are analyzed using Python-based image processing algorithms to identify defects such as leakage or improper sealing. If a defect is detected, a servo motor-based rejection mechanism diverts the faulty product from the conveyor line. Products without defects proceed to the cold plasma sterilization unit, where plasma treatment eliminates microorganisms without affecting food quality.

4.1 System Architecture

The system architecture consists of a conveyor belt system, DC motor drive, USB camera, image processing unit, servo rejection mechanism, and cold plasma sterilization unit. The camera captures product images and sends them to the processing unit where Python algorithms analyze the images for defect detection. Based on the analysis result, control signals are generated to either reject the product or allow it to proceed to the sterilization stage.

4.2 Conveyor Mechanism Design

The conveyor system is driven by a DC motor coupled with a spur gear mechanism to provide controlled speed and torque. The conveyor shaft is supported by bearings to ensure smooth rotation and reduce friction. This mechanism enables continuous movement of packaged products through the inspection and sterilization zones.

4.3 Image Processing Algorithm

The defect detection process is performed using Python-based image processing techniques. The captured images are first converted into grayscale and preprocessed to remove noise. Edge detection and thresholding techniques are then applied to identify surface defects or leakage in the packaging. The algorithm classifies products as either defective or non-defective based on predefined parameters.

4.4 Servo-Based Rejection Mechanism

A servo motor (MG995) is used to reject defective products from the conveyor. When the image processing system identifies a defective package, a control signal is sent to the servo motor, which activates a rejection arm to divert the faulty product from the conveyor path.

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4.5 Cold Plasma Sterilization Unit

The cold plasma unit performs non-thermal sterilization of accepted products. Plasma is generated using a controlled gas supply system, producing reactive species capable of destroying microorganisms on the surface of packaged products. This process improves hygiene and extends product shelf life without affecting packaging integrity or food quality.

V. METHODOLOGY

The proposed system operates through a sequence of automated steps including image acquisition, defect detection, product rejection, and cold plasma sterilization. Packaged products move along the conveyor belt where a camera captures real-time images for inspection. The captured images are processed using Python-based image processing algorithms to identify defects. Based on the detection result, defective products are rejected while acceptable products proceed to the cold plasma treatment stage for sterilization.

5.1 Image Acquisition

In this stage, a USB camera mounted above the conveyor captures real-time images of packaged products as they move through the inspection zone. Proper lighting conditions and fixed camera positioning ensure clear image capture for accurate defect analysis.

5.2 Image Preprocessing

The captured images are processed using Python libraries such as OpenCV. Image preprocessing includes grayscale conversion, noise removal, and image filtering to enhance image quality and prepare it for defect detection.

5.3 Defect Detection Algorithm

The defect detection algorithm analyzes the processed images to identify packaging defects such as leakage, cracks, or improper sealing. Techniques such as thresholding and edge detection are applied to highlight irregularities in the packaging surface. The algorithm then classifies the product as defective or non-defective.

5.4 Automated Product Rejection

When a defect is detected, a control signal is sent to the servo motor-based rejection mechanism. The servo motor activates a rejection arm that diverts the defective product from the conveyor path, preventing it from reaching the sterilization stage.

5.5 Plasma Sterilization Process

Products that pass the inspection stage move to the cold plasma sterilization unit. Plasma is generated using a controlled gas supply system, producing reactive species that eliminate microorganisms on the surface of the packaged product. This non-thermal sterilization process improves hygiene and extends product shelf life without affecting food quality.

VI. EXPERIMENTAL SETUP

The experimental setup was developed to evaluate the performance of the proposed cold plasma conveyor system with leak detection. The system integrates mechanical components, imaging devices, and processing units to perform automated inspection and sterilization of packaged products. The experiment was conducted by placing sample packaged products on the conveyor belt and monitoring the inspection and rejection process using the image processing system.

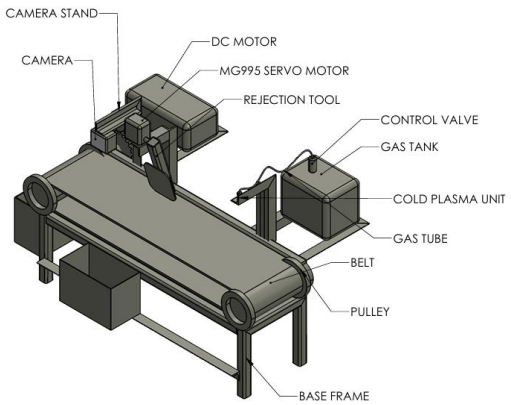

Fig.1 Experimental Setup Image

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6.1 Hardware Components

The hardware setup includes a DC motor-driven conveyor system, USB camera, ESP32 controller, MG995 servo motor for product rejection, and a cold plasma generation unit with a gas supply system. The conveyor transports packaged products through the inspection zone where images are captured and processed. The servo motor is used to remove defective products from the conveyor line.

6.2 Software Implementation

The software system was developed using Python programming with OpenCV libraries for image processing and defect detection. The algorithm captures images from the USB camera, performs preprocessing operations, and detects packaging defects using image analysis techniques. Based on the detection result, control signals are generated to activate the rejection mechanism.

6.3 Testing Environment

The experimental testing was conducted under controlled laboratory conditions with consistent lighting and fixed camera positioning. Different packaged product samples were placed on the conveyor to evaluate defect detection accuracy and system performance. Multiple trials were conducted to analyze efficiency, inspection time, and output quality of the proposed system.

6.4 Circuit Diagram of the Proposed System

The circuit diagram illustrates the electrical connections between the ESP32 controller, DC motor driver, servo motor, camera interface, and cold plasma generation unit. The ESP32 acts as the central control unit that receives signals from the image processing system and controls the conveyor motor and rejection mechanism.

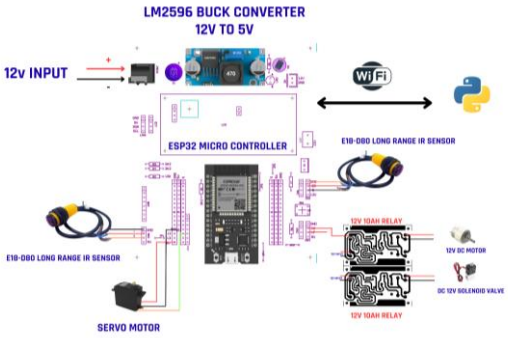

Fig. 2 Circuit Diagram of the Proposed System

VII. RESULTS AND DISCUSSION

Table 7.1 Detection Accuracy Results

Trial	Total Samples Tested	Defective Packets Detected	Detection Accuracy (%)
Trial 1	50	45	91%
Trial 2	50	47	94%
Trial 3	50	48	96%

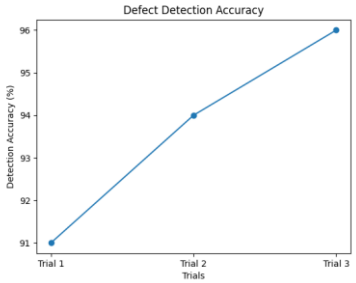

Fig.3 Defect Detection Accuracy Graph

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Table 7.2 Inspection Time Results

Trial	Average Inspection Time (sec)
Trial 1	4.8
Trial 2	4.3
Trial 3	3.9

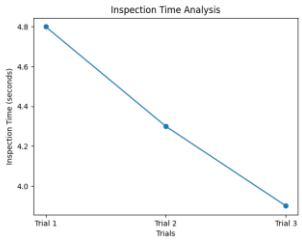

Fig.4 Inspection Time Analysis Graph

Table 7.3 Manual vs Prototype Comparison

Parameter	Manual Inspection	Proposed Prototype
Detection Accuracy	72%	95%
Inspection Time	10 sec	4 sec
Human Dependency	High	Low
Production Efficiency	Moderate	High

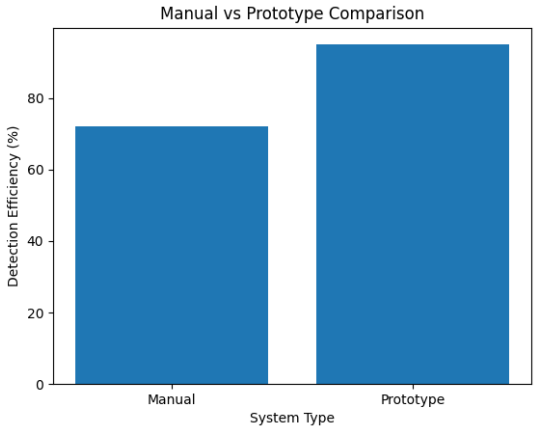

Fig.5 Manual vs Prototype Comparison Graph

VIII. ADVANTAGES OF PROPOSED SYSTEM

The proposed Cold Plasma Conveyor System with Leak Detection using Python-based Image Processing offers several advantages over traditional inspection and sterilization systems. The integration of computer vision technology enables accurate and real-time detection of packaging defects such as leakage, cracks, and improper sealing. Compared to manual inspection, the automated system provides higher detection accuracy and consistent performance without being affected by human fatigue.

Another major advantage is the use of cold plasma technology for non-thermal sterilization, which effectively eliminates microorganisms without affecting food quality, packaging integrity, or nutritional value. The system also reduces human intervention and operational costs by automating inspection and rejection processes. In addition, the conveyor-based automated mechanism improves production speed and ensures continuous processing of packaged products. Overall, the proposed system enhances product safety, improves hygiene standards, and increases industrial productivity.

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IX. APPLICATIONS

The proposed system can be applied in various industrial sectors where packaging inspection and sterilization are essential. Major applications include:

- Food packaging and processing industries
- Dairy product packaging plants
- Meat and poultry processing industries
- Pharmaceutical packaging industries
- Beverage manufacturing industries
- Ready-to-eat food production units
- Hygienic product inspection systems
- Automated industrial production lines requiring quality monitoring

These applications demonstrate the capability of the proposed system to improve food safety and quality control in modern industrial environments.

X. CONCLUSION

This paper presented the design and development of a Cold Plasma Conveyor System with Leak Detection using Python-based Image Processing for automated inspection and sterilization of packaged food products. The proposed system integrates conveyor automation, machine vision inspection, and non-thermal cold plasma sterilization into a single platform. Experimental results showed that the system achieved high defect detection accuracy and reduced inspection time compared to conventional manual inspection methods.

The automated rejection mechanism effectively removed defective products, while the cold plasma unit provided efficient surface sterilization without affecting food quality or packaging integrity. The proposed system significantly improves inspection reliability, reduces labor dependency, and enhances hygiene standards in food packaging industries. Therefore, the developed system provides a cost-effective and scalable solution for modern automated food processing and packaging applications.

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