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Research Original Article

HC-SR04 Sensor Implementation in an IoT-Based Fresh Fruit Bunch Filling Prototype for Vertical Sterilizer

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Abstract

This study develops an IoT-based Fresh Fruit Bunch (FFB) filling prototype for vertical sterilizers using the HC-SR04 ultrasonic sensor to enhance the accuracy and efficiency of the filling process in palm oil mills. The system incorporates a non-contact distance sensor to ensure precise measurement and integrates IoT technology and a Telegram bot for real-time monitoring and automation. Testing results indicated that the HC-SR04 sensor achieved high accuracy, maintaining a low tool failure rate of 0.036%, making it highly reliable for industrial applications. Visual and audio indicators, including LEDs and buzzers, were used to enhance user awareness and safety during the filling process. By automating and optimizing FFB loading, the system minimizes operational inefficiencies commonly associated with manual filling methods and improves safety by reducing human intervention. These findings suggest that the developed prototype can provide significant operational benefits to the palm oil industry and other sectors requiring similar improvements in productivity and sustainability. Future research will focus on refining the prototype and evaluating its scalability for broader industrial use.

Keywords: Fresh Fruit Bunch; IoT; HC-SR04; Vertical Sterilizer; Automation

Introduction

Palm oil mills play a crucial role in the global economy by processing Fresh Fruit Bunches (FFB) to produce palm oil, widely used in the food, cosmetics, and biodiesel industries.[1][2] A key step in this process is the sterilization of FFB in a vertical sterilizer, where FFB is heated to eliminate harmful microorganisms that may affect oil quality.[3] Efficient and accurate filling of FFB into the sterilizer is essential to maintain smooth operations and enhance production efficiency.[4][5] However, the commonly used manual filling methods often lead to imbalances in filling amounts and operational inefficiencies, which negatively impact productivity.[6]

To address these challenges, modern technologies such as the HC-SR04 ultrasonic sensor and the Internet of Things (IoT) can offer effective solutions.[7][8] The HC-SR04 sensor enables accurate, non-contact distance measurement, while IoT provides a platform for real-time monitoring and control of the filling process.[9] IoT is a concept in which physical devices are connected to the internet.[10][11] allowing them to communicate and share data for automation and increased operational efficiency [12] In the industrial sector, implementing IoT has the potential to improve efficiency, reduce costs, and minimize the risk of human error, which is highly relevant for the palm oil industry as it faces digital transformation.[13][14]

This study aims to evaluate the application of the HC-SR04 ultrasonic sensor in an IoT-based FFB filling system within a vertical sterilizer.[15] This system is designed to enhance filling accuracy and efficiency by leveraging sensor and IoT integration, enabling remote monitoring and real-time process automation. The expected outcomes are increased productivity, reduced long-term operational costs, and improved workplace safety. Findings from this study could provide a significant contribution to the palm oil industry and other sectors requiring similar automation to improve operational efficiency and sustainability.

Literature Review

Sterilizer Vertical

A vertical sterilizer is a device used in palm oil processing to sterilize Fresh Fruit Bunches (FFB) through steaming in a vertically oriented chamber. This design promotes efficient steam distribution and gravity-assisted loading and unloading, reducing energy consumption and sterilization time [15]. Vertical sterilizers are valued for their space efficiency, reduced maintenance costs, and ability to improve soil quality by eliminating harmful microorganisms. They are increasingly popular in the palm oil industry for enhancing productivity and supporting sustainable practices [16].

Internet of Things

The Internet of Things (IoT) refers to a network of physical devices connected to the Internet, enabling them to collect, share, and analyze data. IoT devices, embedded with sensors and software, can communicate autonomously, allowing real-time monitoring, automation, and remote control.[17] IoT is widely applied in industries such as healthcare, agriculture, and smart homes, where it enhances efficiency, reduces costs, and enables data-driven decision-making, making it a key component in modern technological advancement.[18]

Telegram

Telegram is a cloud-based messaging platform that focuses on speed, security, and extensive features. It allows users to send messages, multimedia, and files with end-to-end encryption through Secret Chats, enhancing user privacy. Telegram also supports bots, channels, and groups, enabling automation, large-scale communication, and community-building [19]. With APIs for integration, Telegram is commonly used in IoT projects and automation due to its reliability and real-time communication capabilities, making it popular for both personal and professional use.[20]

HC-SR04 Ultrasonic Sensor

The HC-SR04 is an ultrasonic sensor used for non-contact distance measurement.[21] It emits ultrasonic waves from a transmitter, which bounce back upon hitting an object. The sensor calculates the distance based on the time taken for the waves to return to its receiver.[14] With a range of 2 cm to 400 cm and a tolerance of ±3 mm, the HC-SR04 is widely used in applications like robotics and IoT for reliable, real-time distance monitoring.

LCD I2C 16x2

The LCD I2C 16x2 is a 16-column by 2-row display module with an I2C interface, making it easier to connect to microcontrollers with minimal wiring.[8] It displays characters and symbols, commonly used in embedded systems to show data such as sensor readings, time, or status messages. The I2C interface allows multiple devices to communicate over a single bus, reducing pin usage and simplifying setup. The LCD I2C 16x2 is widely used for real-time data display in projects with microcontrollers like Arduino and ESP32.[7]

Buzzer

A buzzer is an electronic component that produces sound when an electric current passes through it.[22] Commonly used for alerts and notifications, buzzers are often found in systems requiring audio feedback, such as alarms, timers, and control panels. They come in two types: active buzzers, which produce sound when powered, and passive buzzers, which require an external frequency to generate sound.[23] Buzzers are widely used in electronics projects to signal conditions or warnings due to their simplicity, low power consumption, and ease of integration.[8]

LED

An LED (Light Emitting Diode) is a semiconductor device that emits light when an electric current flows through it.[24] LEDs are energy-efficient, have a long lifespan, and come in various colors and brightness levels. They are widely used as indicators, in displays, and for illumination in a range of electronics and IoT projects.[1] LEDs are favored for their low power consumption, quick response time, and durability, making them ideal for applications where visual signals or status indicators are required.

Materials & Methods

Research Procedure

The research procedure is illustrated in flowcharts designed to make the research process more effective. Two flowcharts are required: the first is for prototype development and the second is the block diagram of the fresh fruit bunch filling system prototype, as shown in the following figures.

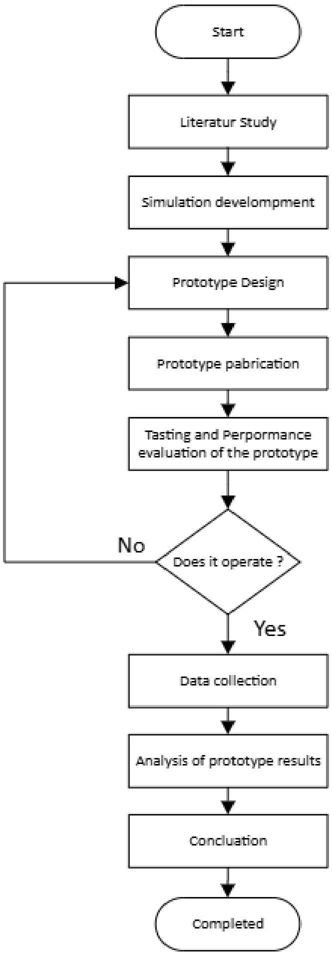

Figure 1. Research Flow Diagram

The following is a flowchart that describes the process of making a Vertical Sterilizer prototype system.

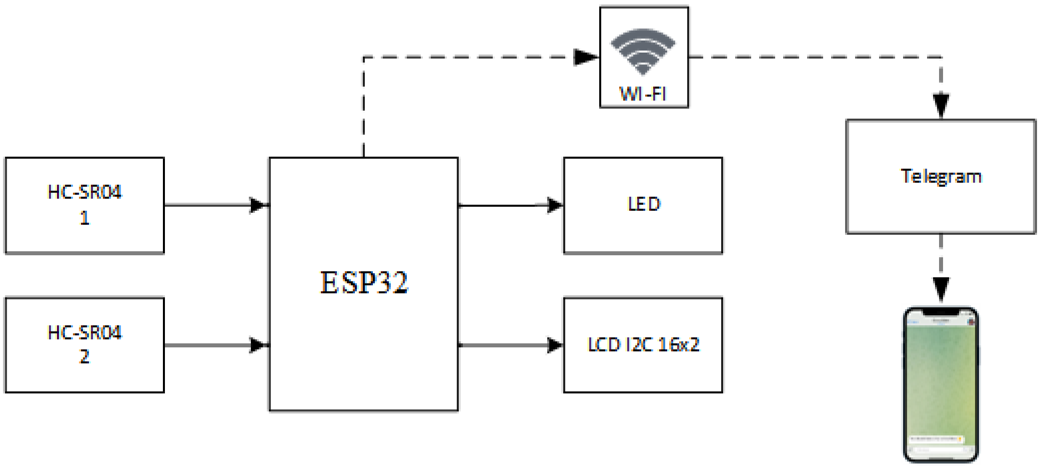

Figure 2. System Flow Diagram

Data Collection Method

Data collection in this study consists of the following steps: (1) Literature Review, which involves gathering relevant literature for this research; (2) Prototype Simulation, aimed at testing and optimizing the design before physical implementation; (3) Prototype Design, which includes planning the shape and materials for the prototype; (4) Prototype Construction, where the prototype is built according to the planned design, including the assembly of the prototype frame, HC-SR04 Ultrasonic Sensor, Drum, I2C 16x2 LCD, Buzzer, LED, and overall installation; (5) Testing and Performance Evaluation of the Prototype, which includes conducting tests on the prototype during the fruit filling process and recording the results; (6) Data Collection, where the performance data and characteristics of the prototype are recorded; (7) Data Analysis and Prototype Evaluation, where observations are made to assess aspects that are working well and those that need improvement; and (8) Conclusion.

Design of the Vertical Sterilizer Prototype

1) 30-Liter Capacity Drum

The 30-liter capacity drum is the main component of the vertical sterilizer prototype designed for the efficient filling of Fresh Fruit Bunches (FFB). Made from durable materials, this drum is intended to hold FFB during the filling process.

Table 1. Drum specification

Feature	Specification
Height	26 cm
Diameter	30 cm
Weight	2 kg

2) HC-SR04 Ultrasonic Sensor

The HC-SR04 ultrasonic sensor is a crucial component in the vertical sterilizer filling prototype, used for accurately measuring the distance to the Fresh Fruit Bunches (FFB) during the filling process. This sensor operates by emitting ultrasonic waves and measuring the time it takes for the waves to reflect from the surface of the FFB. The specifications are as follows.

Table 2. HC-SR04 Ultrasonic sensor

Feature	Specification
Voltage	DC 5V
Current	15mA
Frequency	40Hz
Maximum Rang	4m
Minimum Range	2cm
Measurement Angle	15 degrees
Trigger Input Signal	TTL pulse 10µS
Echo Output Signal	TTL signal and proportional range
Dimensions	45 * 20 * 15mm

3) LCD I2C 16x2

The 16x2 I2C LCD is a crucial component in the vertical sterilizer filling prototype, designed to display real-time information regarding the filling process of Fresh Fruit Bunches (FFB). This LCD features a 16-character by 2-line display, allowing for the visualization of important data such as distance measurements, filling status, and system alerts. The specifications are as follows.

Table 3. LCD 12C 16x2

Feature	Specification
Power	DC 5V
Supports LCD 1602 and 2004 (LCD 16x2, LCD 16x4)	
Control pins	SDA and SCL
Built-in potentiometer for adjusting brightness	
Built-in jumper to disable backlight	
Dimensions	40mm x 18mm

4) Buzzer

The buzzer functions as an audio notification device in the sterilizer filling prototype. This component emits sound signals that indicate various statuses during the filling process of Fresh Fruit Bunches (FFB). With the sound produced, the buzzer assists the operator in monitoring the filling conditions, such as when the FFB has reached a certain level or if there is an error in the process. The specifications used are as follows.

Table 4. Buzzer

Feature	Specification
Input voltage range	DC 3-24V
Rated voltage	12V

Frequency	3000+/-500 Hz

5) Light Emitting Diode (LED)

The Light Emitting Diode (LED) functions as a visual notification device in the form of light in the sterilizer filling prototype. This component provides visual signals that indicate various statuses during the filling process of Fresh Fruit Bunches (FFB). The LED can light up in different colors to indicate specific conditions, such as a green light to signify that the filling is proceeding well, or a red light to warn of errors or issues in the process. The specifications are as follows.

Table 5. Light Emitting Diode (LED)

Feature	Specification
Color	Red
I_FMax	30mA
V_F	1.7 V
V_R max	5 V
Luminous intensity	5mcd @ 10mA
Viewing angle	60°
Wavelength th	660nm

Prototype Frame Diagram

Below is the diagram of the prototype frame created using SketchUp software:

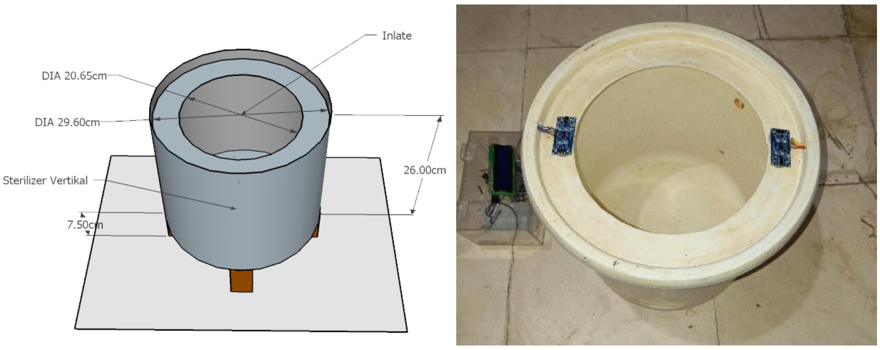

Figure 3. Design and Prototype

An electronic circuit in a vertical sterilizer prototype

Below is the electrical system and sensor design on the prototype:

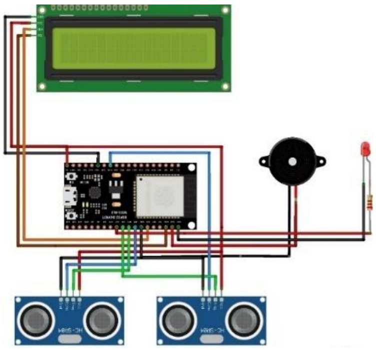

Figure 4. Electronic circuit

Results and Discussion

Testing of the HC-SR04 Sensor on the Prototype

This sensor is used to measure the distance between the sensor and the surface of the TBS inside the sterilizer. The test results of the HC-SR04 sensor indicate that it can measure distance with good accuracy in an ESP32-based system. The testing was conducted by connecting the sensor to the microcontroller and checking the measured distance in various scenarios. The trials were carried out 5 times, as shown in the following Table 6.

Table 6. Testing of the HC-SR04 on the prototype

Actual Distance (cm)	Measurement 1 (cm)	Measurement 2 (cm)	Measurement 3 (cm)	Average (cm)	Errors (%)
26	26.01	25.81	25.97	25.93	0.002
21	20.71	20.54	20.22	20.49	0.01
16	16.21	16.01	16.08	16.1	0.006
11	10.17	10.15	10.86	10.3	0.06
6	6.02	5.86	5.92	5.93	0.01
Average tool failure					**0.036 %**

The test results show that the HC-SR04 sensor is capable of detecting changes in distance effectively. The data obtained from the sensor were recorded and analyzed to evaluate the correlation between the measured distance and the actual distance. The tests were conducted ten times to ensure the reliability of the results. Each distance reading was displayed on the LCD and also sent to the Telegram bot to ensure that users received accurate and up-to-date information. Overall, this testing aims to assess the effectiveness of the HC-SR04 sensor in prototype applications, as well as to identify potential improvements or adjustments needed to enhance the accuracy of distance measurements.

Jarak Buah Terisi Saat Ini: 10.51 cm
Status: Buah Terisi. 10:05 PM

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Jarak Buah Terisi Saat Ini: 10.51 cm
Status: Buah Terisi. 10:06 PM

Jarak Buah Terisi Saat Ini: 10.51 cm
Status: Buah Terisi. 10:06 PM

Jarak Buah Terisi Saat Ini: 10.51 cm
Status: Buah Terisi. 10:06 PM

Jarak Buah Terisi Saat Ini: 10.51 cm
Status: Buah Terisi. 10:06 PM

(a) (b) (c)

(a) fruit filling process, (b) Distance data display on LCD, (c) Displays distance data and fruit charging status and includes everything in the Telegram bot.

Figure 5. Telegram and LCD I2C 16x2

Conclusions

The implementation of the HC-SR04 ultrasonic sensor in an IoT-based system for the vertical sterilizer prototype demonstrated effective and accurate distance measurement capabilities. The integration of real-time monitoring and automation, facilitated by IoT technologies and Telegram, enabled a more efficient filling process for Fresh Fruit Bunches (FFB) in the palm oil industry. Testing results indicated minimal tool failure and consistent performance, which significantly enhances the filling accuracy and reduces operational costs. Additionally, the use of visual and audio indicators, such as LEDs and buzzers, contributed to improving safety and user awareness. These findings suggest that the developed system could serve as a reliable model for further automation initiatives within the palm oil processing sector and other industries requiring similar improvements in operational efficiency and productivity. Future work should focus on refining the prototype to address any limitations and exploring the scalability of the system in larger industrial settings.

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