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Implementation of Smart Onion Counting and Environmental Sensing System with ESP32 MCU

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ABSTRACT

The rapid development of embedded system technology in recent decades has had a significant impact, this advancement has contributed to an increase in production capacity with real-time monitoring through embedded system MCU ESP32. The process of manufacturing onion products, such as fried shallots and garlic. The objective of this research is to develop a low-cost automatic onion counting system that utilizes an embedded system MCU ESP32 with integration of infrared sensors, temperature and humidity sensors to monitor production quality conditions in real-time for small scale Industry. Using the engineering design method, where the TCRT5000 sensor is employed to detect objects based on infrared light interruption, and environmental conditions are measured with the DHT22 sensor to maintain production quality. The internet connection for wireless communication for transmitting data to a mobile device through google firebase. Analysis was performed to evaluate performance such as, data transmission response time, and environmental sensor precision. The results obtained demonstrate that the system attained counting accuracy rates of 98.2% for garlic and 98.55% for shallots. with average data transmission response times of 1.51 seconds and 1.89 seconds, respectively, achieving a success rate of 97.15%. The environmental monitoring sensors demonstrated a high degree of accuracy, with a margin of error of 0.18 °C for temperature and 0.3% for humidity. The results show that this system works effectively in automating onion counting and monitoring, with an accuracy rate of over 98% and a response time of less than 2 seconds, making it suitable for small-scale automated production.

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1. INTRODUCTION

The process of manufacturing onion products, especially in calculating of those raw materials remain a significant challenge for many small and medium-sized enterprises (SMEs) onion-processing sector in Indonesia, because current onion-processing operations are largely traditional, with peeling performed manually. In daily production activities, the process of calculating such as shallots, garlic, or their processed products is often done manually. As competition in the small industry intensifies, the ability of small industry to maintain consistent quality and production efficiency becomes crucial to the sustainability of their business. Research [1] shows that implementing standardized production processes significantly improves cost efficiency in production time using automation that integration embedded system. In order to surmount these challenges, an automatic counting system solution was developed, based on an embedded system with an ESP32 MCU. This is specifically designed for ease of implementation and cost efficiency. The system incorporates infrared sensors to facilitate precise onion counting and environmental sensors to ensure the real-time monitoring of storage conditions. The system's affordability and adaptability to different environments are significant advantages, as it can be integrated into small and medium-scale production lines without the need for substantial infrastructure investments. Consequently, businesses can enhance inventory accuracy, reduce reliance on manual labor, and uphold onion quality through continuous monitoring. This is facilitated by competitive implementation costs and ease of use, supported by an intuitive interface with the development of the Internet of Things (IoT) and mobile device platform, Several studies have proven that sensor technology can assist in automatically and efficiently counting objects. For example, [2] designed an infrared sensor-based coffee bean counting system, while [3] used light sensors to count grain harvests. [4] also developed a temperature and humidity monitoring system[5] using microcontrollers to maintain the quality of food products during storage. On the other hand, [6] emphasized the importance of the latest wireless communication in automation systems, as it can accelerate the process of sending data from devices to servers and displaying it to users. This system provides important benefits and contributions, allowing users to determine the capacity and results of the production process to predict the supply needs of customers or consumers of processed onions. Most studies still focus on a specific function, such as counting or monitoring, without combining both in an integrated system. Few studies have specifically examined the automation of onion raw material counting integrated with simultaneous environmental condition monitoring. Therefore, this study attempts to bridge this gap by developing a low-cost automatic onion counting[7], [8] system that utilizes infrared sensors as the primary detector, combined with temperature and humidity sensors, and equipped with a wireless communication module for real-time data transmission [9]to mobile devices integrated with onion peeling machines. This research is based on the hypothesis that implementing an integrated sensor-based automatic counting system can provide the high accuracy and reliability of environmental monitoring required by onion processing SMEs. With the application of this simple but effective technology, it is hoped that this research can bring about innovation in the form of an integrated IoT-based system design (appropriate technology), especially for processed onion products, which are still rarely researched in the context of food SMEs in Indonesia.

2. METHOD

This research employs an engineering design methodology to develop an integrated Internet of Things (IoT) system, combining hardware and software components for real-time data acquisition and visualization. The system utilizes an ESP32 microcontroller to facilitate sensor data reading [10], which is subsequently transmitted to a Firebase cloud platform for storage and real-time access. Finally, the data is retrieved and displayed through a smartphone application developed using MIT App Inventor, offering a seamless user experience in monitoring and visualizing the collected environmental data. This approach ensures a robust, scalable, and user-friendly solution, making it ideal for IoT applications in various domains.

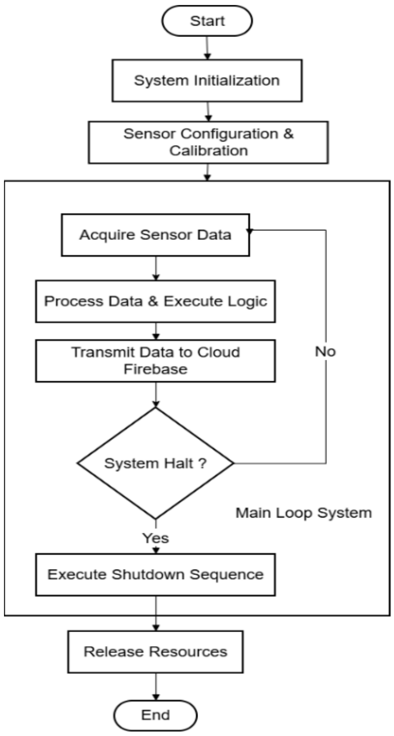


Figure 1. System Architecture of the IoT Solution for Real-Time Data Acquisition and Visualization

On figure 1 presents the workflow of the IoT system, beginning with data collection through the ESP32 microcontroller unit (MCU)[11], which interfaces with various sensors. The gathered data is securely sent to the Firebase cloud platform, allowing for seamless storage and real-time access. From there, the data is retrieved and visualized through a user-friendly smartphone application built using MIT App Inventor, offering an intuitive interface for real-time monitoring of environmental variables. The system enables users to monitor various parameters remotely, ensuring efficient data tracking, analysis, and decision-making for optimized environmental management.

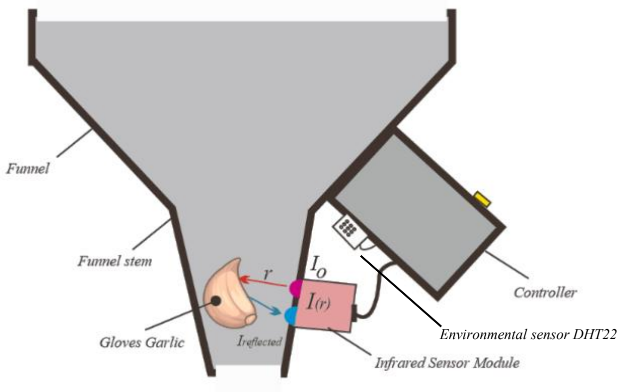


Figure 2. Design sensor integration with the controller

This figure 2 illustrates the integration of the sensors with the controller system. The sensor infrared TCRT5000, the intensity of the infrared radiation emitted by objects is mainly a function of their temperature[12], placed sideway position of the garlic cloves, detects the infrared reflection as the cloves pass through the detection zone, to calculate the number of onions, use the following equation[13][14].

$$I(r) = \frac{I_0}{r^2} \tag{1}$$

$$I_{reflected} = \rho \cdot I(r) \tag{2}$$

Where $I(r)$ is the intensity of the emitted light at the object's surface, I_0 is the initial intensity of the infrared light emitted from the sensor, and r is the distance between the infrared light source and the object. $I_{reflected}$ is the intensity of the reflected infrared light. ρ is the reflectivity of the object's surface. infrared temperature measurement system[15]

$$V_{out} = k \cdot I_{reflected} \tag{3}$$

To connect the infrared sensor output to the controller, use the following sensor output voltage measurements, $V_{out}$is the output voltage from the sensor. k is a constant that relates the intensity of the reflected light to the voltage output of the sensor.

$$V_{threshold} = \alpha \cdot V_{max} \tag{4}$$

Then $V_{threshold}$ is the voltage value above which you consider an object to be detected. V_{max} is the maximum sensor output (typically 3.3V for ESP32's analog input range), and α is a coefficient (typically between 0.5 to 0.8), which defines how sensitive the threshold is[16],

$$V = \left(\frac{ADC\_value}{4095}\right) \cdot V_{max} \tag{5}$$

For $V_{threshold}$ on ESP32 MCU, adjustments are made to the internal ADC reading level, *ADC_Value* is the value read by the internal ESP32 ADC (ranging from 0 to 4095). $V_{max}$is the maximum voltage (typically 3.3V for ESP32). Therefore, the above equation is required to obtain a more accurate sensor reading.

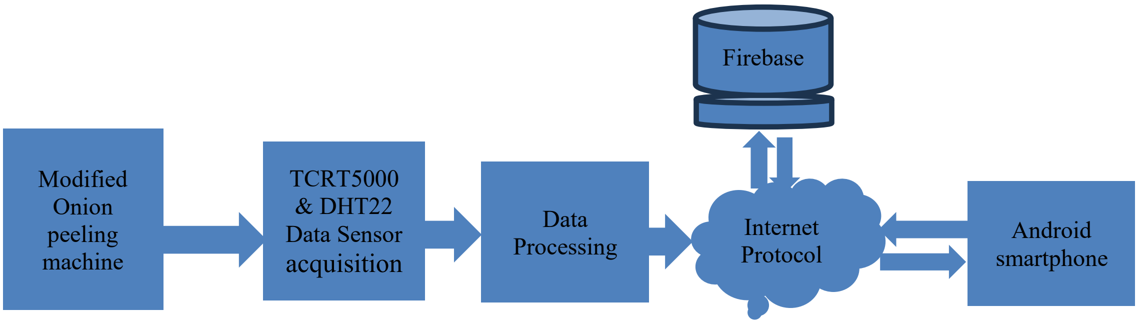
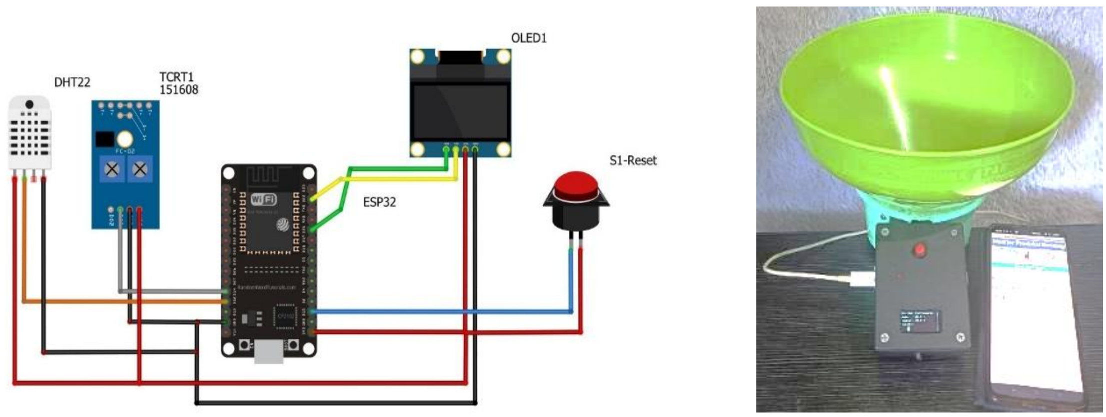


Figure 3. workflow system of the IoT system

On Figure 3 illustrates the workflow system of the IoT system. Data acquisition is initiated through sensors that capture environmental data and data counter, which is subsequently processed. After processing, the data is transmitted to the Firebase cloud platform via the internet for secure storage. The processed data is then accessed through an Android smartphone application, enabling real-time monitoring and interaction with the data. This system architecture ensures seamless data flow from sensor input to user interface, providing efficient, accessible, and real-time data analysis for end user.



(a) (b)

Figure 4. (a)Wiring diagram of the system; (b) integration hardware and mobile device monitor system

Figure 4 (a) shows the circuit wiring diagram of the system, which uses a TCRT5000 module as an infrared counter and a DHT22 sensor module to monitor temperature and humidity during production for optimal results. The process is displayed on an SSD 1306 OLED display module to show the Wi-Fi protocol connection status and the readings from the infrared sensor and DHT sensor in real time, along with a reset button. Setting up the ESP32 and connecting it to different sensors[17]. Figure 4 (b) illustrate hardware assembly and integration system with all component sensor input data MCU ESP32 case, display the measurement data and send it to the Firebase cloud database, the system provides a remote monitoring interface, accessible via a dedicated Android application over an internet connection.

3. RESULTS AND DISCUSSION

In this section, the research findings are presented, accompanied by a detailed analysis of the collected data. Each result is examined thoroughly, addressing the implications, challenges, and successes encountered in developing a cost-effective automation system for small-scale onion processing, utilizing an IR sensor-based counter and environmental monitoring.

3.1. Counting Accuracy of Onion Products

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The accurate counting of raw materials is imperative for maintaining consistency in production and ensuring cost optimization. The present study evaluated the performance of the automatic onion counting system by measuring its counting accuracy for onion. Furthermore, the performance evaluation assesses potential errors and deviations in the automated counting process, offering insights into system limitations. Recommendations for system improvements focus on enhancing counting precision and overall operational efficiency.

Table 1. The performance of counting accuracy

Experiment No.	Target Count (Pieces)	Shallots Correct	Shallots Failures	Shallots Failures (%)	Garlic Correct	Garlic Failures	Garlic Failures (%)
1	110	108	1	0.91%	108	3	2.73%
2	110	109	3	2.73%	108	1	0.91%
3	110	106	2	1.82%	108	3	2.73%
4	110	108	1	0.91%	107	1	0.91%
5	110	108	2	1.82%	109	3	2.73%
6	110	109	2	1.82%	109	3	2.73%
7	110	106	2	1.82%	109	1	0.91%
8	110	106	2	1.82%	109	1	0.91%
9	110	108	1	0.91%	108	3	2.73%
10	110	107	1	0.91%	107	2	1.82%
11	110	108	2	1.82%	107	1	0.91%
12	110	108	2	1.82%	108	2	1.82%
13	110	108	1	0.91%	107	2	1.82%
14	110	108	1	0.91%	108	2	1.82%
15	110	109	1	0.91%	109	1	0.91%
			Average	**1.45%**			**1.76%**

At table 1, in the case of garlic, an accuracy rate average of 98.2% corresponds to approximately 108 out of 110 garlic pieces being counted correctly, representing the failure count. For shallots, the accuracy rate average of 98.55% indicates that around 107 out of 110 shallots are counted accurately, leaving a failure count of 3 shallots, calculated as the difference between the target count and the correctly counted pieces. This Failure occur due machine vibration during experiment.

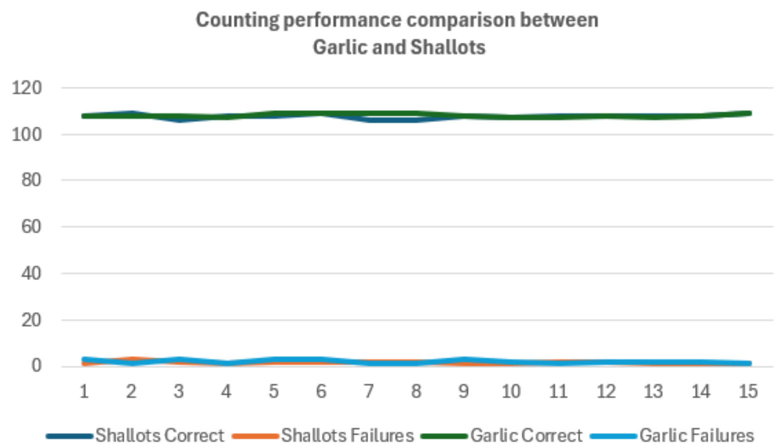


Figure 5. comparison accuracy count between garlic and shallots

The graph on figure 5 presents a comparison of the counting performance between garlic and shallots. Both the correct and failure counts for garlic and shallots remain fairly consistent across the trials. The "Garlic Correct" line stays steady just below 120, while "Shallots Correct" fluctuates slightly around the same value.

The failure counts for both garlic and shallots are minimal, showing only a slight increase. This indicates that the counting accuracy for both garlic and shallots was comparable, with a minimal number of errors observed.

3.2. Data Transmission and Response Time

As demonstrated by the data presented in Table 2, it is evident that the success rate across all 15 experiments remains consistently high, ranging from 95.45% and data transmission through the machine peel to the Android handheld device monitor system.

Table 2. The performance of transmission and response time

Experiment No.	Target Count (Pieces)	Response Time (sec)	Success Count	Failure Count	Success Rate (%)
1	110	1.65	108	2	98.18%
2	110	1.88	106	4	96.36%
3	110	1.79	106	4	96.36%
4	110	1.74	107	3	97.27%
5	110	1.56	108	2	98.18%
6	110	1.56	105	5	95.45%
7	110	1.52	108	2	98.18%
8	110	1.85	110	0	100.00%
9	110	1.74	106	4	96.36%
10	110	1.78	105	5	95.45%
11	110	1.51	108	2	98.18%
12	110	1.89	110	0	100.00%
13	110	1.83	106	4	96.36%
14	110	1.58	105	5	95.45%
15	110	1.57	105	5	95.45%
				Average	**97.15%**

On Table 2 the average success rate of 97.15% is indicative of strong and stable performance, suggesting that the system or process under evaluation is highly dependable.

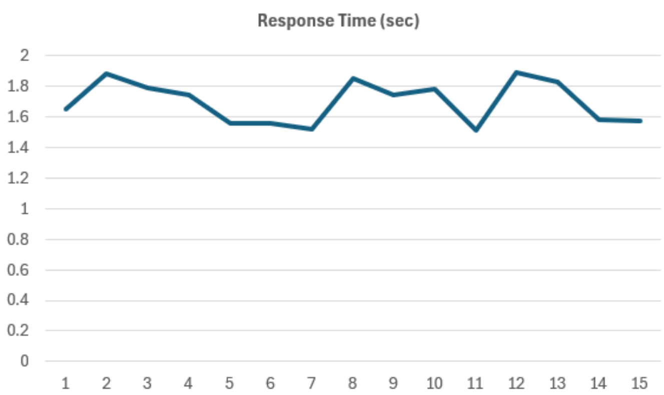


Figure 6. system response time

The figure 6 show how system time transmission data, where the data shows a response time of less than 2 seconds, is classified as good and responsive, which is the low incidence of failures observed in each experiment serves to emphasize the reliability of the system. Furthermore, the response time exhibits minimal variability, contributing to the enhancement of the system's overall efficiency and consistency.

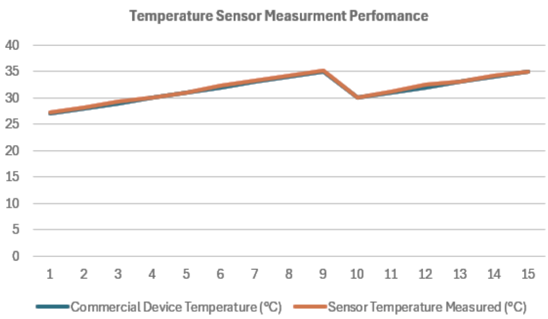
3.3. Environmental Sensor Performance

The following is a measurement experiment. These sensors are evaluated based on their accuracy, margin of error, and consistency.

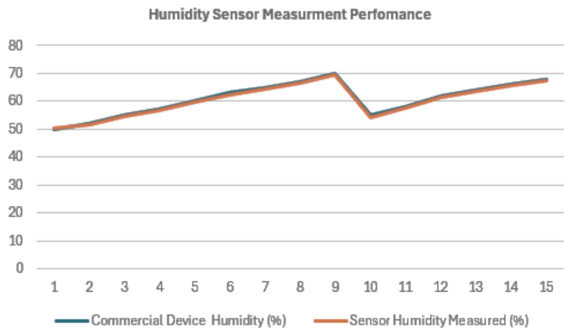
Table 3. comparison of environmental sensor measurements

Experiment No.	Commercial Device Temperature (°C)	Commercial Device Humidity (%)	Sensor Temperature Measured (°C)	Temperature Error (°C)	Sensor Humidity Measured (%)	Humidity Error (%)
1	27	50	27.2	0.2	50.5	0.5
2	28	52	28.1	0.1	51.8	0.4
3	29	55	29.3	0.3	54.6	0.4
4	30	57	30.1	0.1	56.9	0.1
5	31	60	31	0	59.8	0.2
6	32	63	32.4	0.4	62.5	0.5
7	33	65	33.2	0.2	64.3	0.7
8	34	67	34.3	0.3	66.7	0.3
9	35	70	35.1	0.1	69.5	0.5
10	30	55	30	0	54.2	0.8
11	31	58	31.2	0.2	57.8	0.2
12	32	62	32.5	0.5	61.6	0.4
13	33	64	33.1	0.1	63.8	0.2
14	34	66	34.2	0.2	65.9	0.1
15	35	68	35	0	67.5	0.5
Average				**0.18**		**0.39**

From table 3 above, the performance of the environmental sensors was evaluated across 15 experiments, measuring temperature and humidity. The average temperature error was found to be 0.18°C, indicating a high level of precision in the sensor's temperature measurement.



(a)



(b)

Figure 7. (a) Temperature sensor performance; (b) humidity sensor performance measurement

Figure 7 (a) and (b), show how sensor perform, the average humidity error was 0.39%, demonstrating consistent and reliable performance in humidity measurements. These results confirm that the environmental sensors exhibit strong accuracy, with minimal error margins for both temperature and humidity, making them suitable for accurate monitoring in a variety of applications.

3.4. System Integration and Feasibility

The integration of various sensors and technologies into a unified system has the potential to revolutionize production processes, particularly in industries where raw material estimation plays a critical role in maintaining product quality and profitability. The integration of various sensors and technologies into a unified system has the potential to revolutionize production processes, particularly in industries where raw material estimation plays a critical role in maintaining product quality and profitability. By leveraging real-time data, these systems can enhance accuracy in material forecasting, minimize waste, and optimize resource allocation, leading to greater operational efficiency and cost-effectiveness. This approach ensures better decision-making and supports sustainable practices within the production lifecycle.

(a) (b)

Figure 8. (a) Modified peeling machine; (b) field testing of the system at onion processing SMEs

On figure 8 In the context of onion processing, the challenge of accurately counting raw materials such as garlic and shallots is crucial to avoid production cost discrepancies. The low-cost automatic onion counting system presents a promising solution, leveraging infrared (IR) sensors for object detection in conjunction with temperature and humidity sensors to monitor real-time production conditions. This integration aims to streamline the production process, minimize human error, and optimize overall operational efficiency.

From a systems integration perspective, the seamless operation of the IR sensor TCRT5000, for counting, combined with environmental monitoring via the DHT22 sensors, highlights the potential for a robust and reliable production tool. The IR sensor's role in detecting interruptions in infrared beams allows for precise counting, while the environmental sensors provide crucial real-time data to ensure optimal production conditions. These features, integrated with wireless communication capabilities, facilitate data transmission to mobile devices, enabling remote monitoring and control.

4. CONCLUSION

This research successfully demonstrates a cost-effective automated system for onion by integrating infrared sensors for object detection and temperature and humidity sensors for real-time environmental monitoring. The system demonstrated high accuracy, with counting rates of 98.2% for garlic and 98.55% for shallots, and average data transmission response times of 1.51 seconds for garlic and 1.89 seconds for shallots. Environmental sensors showed an error margin of 0.18°C for temperature and 0.39% for humidity. This IoT-based solution offers a reliable, automated alternative to manual counting, improving production efficiency and reducing raw material discrepancies. The system is ideal for small-scale food processing SMEs, providing an effective and simple way to maintain consistent quality and profitability. The system's performance in field tests demonstrates notable robustness and efficacy, confirming its practical viability. This research underscores the potential of low-cost IoT technologies to modernize foundational food production processes, offering a tangible pathway to improve operational resilience and sustainability.

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