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Development of an IoT-Based Chicken Manure Management System Prototype for Efficiency and Sustainability

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Abstract: Increasing the production scale of laying hen farms results in significant manure waste, thus posing challenges to animal and human health, as well as environmental quality. To address these issues, this study aims to develop a prototype of an Internet of Things (IoT)-based multilevel manure management system to improve operational efficiency and support farm sustainability. The study used a method that included needs analysis, design, implementation, and testing with a black box testing approach. The system was designed using the DS3231 RTC module for automatic scheduling, the MQ2 sensor for air quality detection, the ESP8266 microcontroller as the control center, the BTS7960 driver as the current regulator, and the DC motor and conveyor as actuators that drive manure removal, with monitoring results displayed on the LCD. The test results showed that all components functioned as designed, the RTC was able to execute the schedule on time, the MQ2 sensor detected the gas threshold accurately, the ESP8266 processed data and sent instructions properly, the BTS7960 delivered a stable current, the DC motor and conveyor worked according to the set duration. This study provides practical implications for modern farm management through the application of the environmentally friendly smart farming concept.

Keywords: Automation, Farming, IoT, Smart, Waste Management

1. INTRODUCING

Laying hens play a crucial role in egg and meat production, contributing significantly to meeting the need for animal protein. Eggs also dominate egg products for public consumption. According to 2022 BPS data, there were 456,802 laying hens in Pesawaran Regency, with demand for eggs increasing by 5% annually [1], [2]. Laying hen farming has several advantages, including: 1) it has become a business sector accepted and developed by the community; 2) cultivation technology has been mastered; 3) it supports agricultural and fisheries businesses; 4) it is a mainstay commodity for the community in meeting nutritional needs; 5) capital turnover is relatively fast; and 6) it can accommodate a large workforce, especially in rural areas [3].

The increasing scale of production in chicken farming generates significant waste that poses environmental and health challenges. Waste management is crucial to reduce negative impacts on human health, livestock, and the environment. Studies have shown that improper waste disposal can increase serious health risks, including respiratory problems due to airborne pathogens and other detrimental effects on water and soil systems [4], [5]. A significant number of farmers are aware of the health and environmental hazards posed by waste. Begum et al. reported that 58% of farmers in the

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Mymensingh and Khulna regions of Bangladesh understood that improper waste management could harm environmental health [6].

The laying hen farming sector faces challenges in waste management, particularly in managing livestock manure, which can negatively impact the environment and animal health [7]. Improperly managed livestock manure can negatively impact the environment and animal health. Excessive accumulation of manure can lead to increased levels of ammonia in the air, potentially reducing air quality inside the barn and triggering respiratory problems in livestock [8]. Furthermore, poorly managed waste can contaminate groundwater sources and lead to the spread of dangerous pathogens, increasing the risk of disease for animals and humans [9].

The integration of smart farming solutions is crucial in optimizing waste management processes. Smart farming techniques leverage Internet of Things (IoT) technology to improve the monitoring and management of agricultural practices, which can significantly reduce waste generation and improve resource allocation[10], [11]. For example, sensors can provide real-time data on environmental conditions [12], enabling farmers to optimize feed distribution [13], manage waste automatically [14], and maintain overall operational efficiency, as well as ensuring that waste is processed sustainably [15]. Pebriansyah et al. reported successfully creating basic automation of chicken coops through temperature control, scheduled feeding, and manure cleaning using Arduino and environmental sensors. The system developed was still a single-layer manure management system, with manure cleaning carried out periodically based on time without considering adaptive environmental quality or sustainable waste management [16]. On the other hand, Firmansyah et al. conducted a similar study that focused on the development of a sensor- and microcontroller-based livestock automation system with the aim of improving livestock comfort and operational efficiency. However, this study still had limitations in the aspect of manure management, which was treated as a supporting function, rather than as a main subsystem designed structurally and layered[17]. In this study, the authors developed a multi-level manure management system that is fully integrated with IoT technology as the core of the smart farming system. This study not only automates the manure disposal process but also links it to the environmental conditions of the coop, operational efficiency, and the principles of livestock sustainability.

Based on the above, innovation is needed in a more efficient manure management system, through the application of IoT-based technology to monitor and optimize the waste processing process automatically. By continuously integrating new technological innovations into smart farming systems, opportunities will open up to increase productivity, animal welfare and environmental sustainability in the laying hen farming industry. The aim of this research is to produce a model/method for an integrated smart farming system, with a focus on developing a prototype of an IoT-based multi-level manure management system that can improve the efficiency and sustainability of livestock farming.

2. RESEARCH METHODOLOGY

2.1 Research Stages

The stages used in this research are needs analysis, design, implementation and testing [18] as shown in Figure 1.

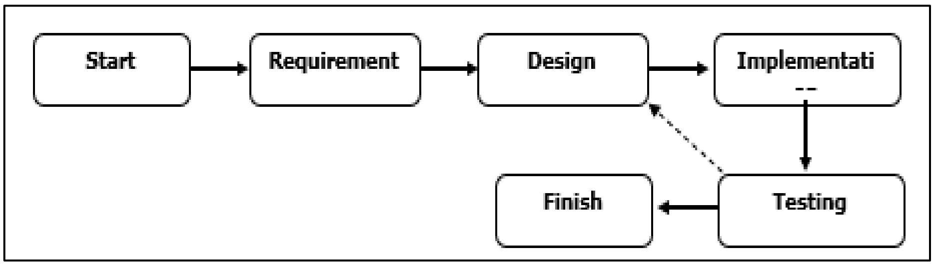


Figure 1. Research Stages

The initial stage in this research is a needs analysis, which aims to identify and evaluate the needs and problems faced in order to determine the objectives, system limitations, constraints, and strategies for solving them. This analysis is conducted to understand the behavior of the system and identify the activities contained within it. Next, hardware and software design are carried out. Hardware design focuses on the development of IoT-based tools that will be used, while software design includes the process of sending data from sensors to the application that functions as a monitoring system. After the design stage is completed, the implementation stage is carried out, where the developed system is translated into programming code so that it can be executed by the machine in the form of a program or program unit that is ready to be operated. The final step is the testing stage, which aims to evaluate whether the developed system meets the established requirements. Testing is conducted using the black box testing method with a focus on system functionality. If the testing shows any discrepancies, the system will be returned to the design stage for improvements. However, if the testing is successful, the system is declared ready for operational use.

2.2 Data

At this stage, data collection and a literature review are conducted, including exploring sensor libraries that support the system implementation process. Literature sources are obtained from various sources, such as books, scientific journals, as well as information from the internet and other relevant sources. The literature used includes datasheets for each electronic component to be implemented in the system. The collected data and literature will form the basis for designing a tool that meets the research needs.

3. RESULT AND DISCUSSIONS

3.1. Requirement

The needs analysis stage is presented in the form of detailed specifications of the tools and materials used, as well as the design of the system's working mechanism. Table 1 shows a list of the tools and materials used in the system implementation.

Table 1. Tools and Materials

No	Hardware	Software
1	NodeMCU ESP8266	Microsoft Windows 8
2	Sensor MQ2	Microsoft Office 2010
3	RTC (Real Time Clock)	Arduino
4	LCD 16x2	Smartphone Samsung Galaxy
5	Adaptor 19V	Google Chrome
6	Regulator Step Down	
7	Driver Motor BTS7960	
8	Motor DC	

The system's working mechanism is controlled by the ESP8266 microcontroller, which acts as a data processing center. The main input comes from two sensors: the DS3231 RTC and the MQ135 sensor. The DS3231 RTC provides time information used to automatically schedule the manure removal process according to predetermined settings. Meanwhile, the MQ135 sensor detects air quality inside the coop, particularly the concentration of hazardous gases. If the sensor detects gas levels exceeding the threshold, the system activates the manure removal mechanism. Data processed by the ESP8266 is displayed on the LCD, allowing farmers to monitor system conditions in real time. When the time or air quality conditions meet the activation criteria, the ESP8266 sends a control signal to the BTS7960 driver, which is equipped with a step-down regulator. This driver is responsible for regulating the power to drive the DC motor, which then activates the conveyor. The conveyor functions to scrape and transport chicken manure to the collection container.

3.2. Design

The design phase includes creating a system block diagram and IoT-based system circuit. Meanwhile, software design includes developing a monitoring system and programming the microcontroller so it can connect to the hardware [19].

3.2.1. System Architecture Design

The block architecture of the monitoring system to be created is explained in Figure 2.

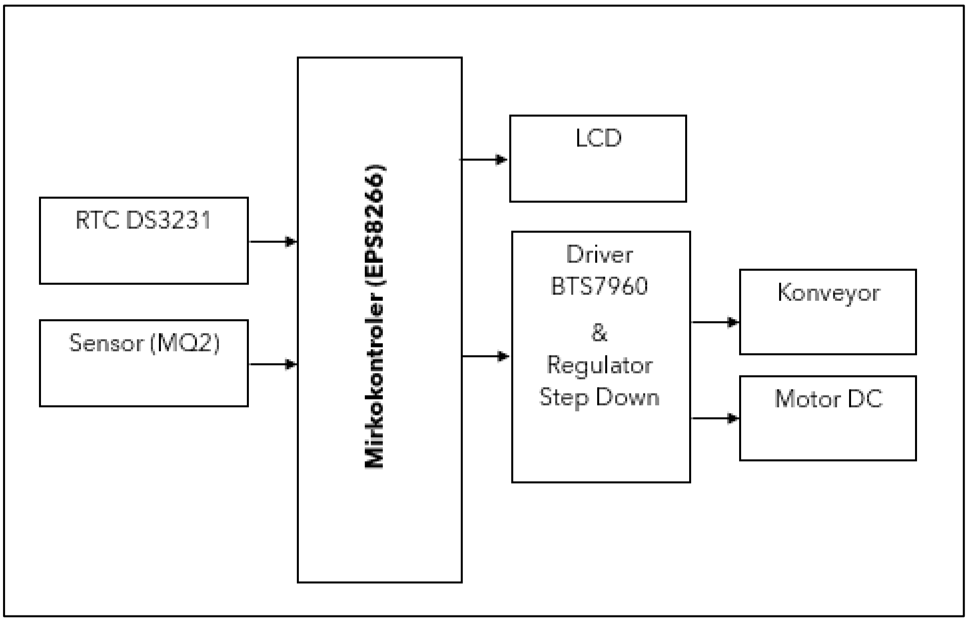
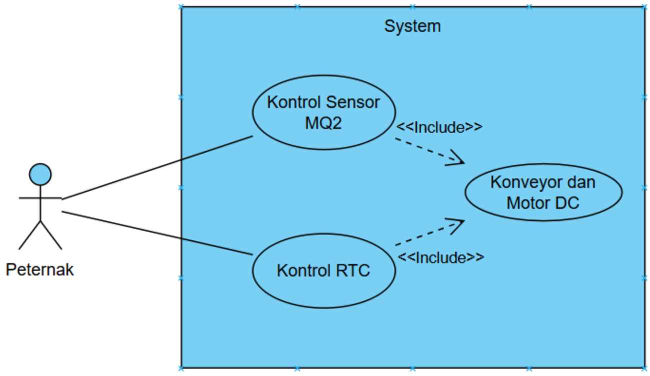


Figure 2. System Block Diagram Architecture

The block diagram in Figure 2 illustrates the architecture of an IoT-based chicken manure management system controlled by an ESP8266 microcontroller as a data processing. The system receives input from two main devices: the DS3231 RTC, which functions as an automatic scheduling time controller, and the MQ2 sensor, which is used to detect air quality, particularly the concentration of hazardous gases in the coop environment. Data received from these two components is processed by the microcontroller to generate control instructions. The output from the ESP8266 is routed to two main paths. First, to the LCD, which displays information on system conditions and sensor detection results in real time. Second, to the BTS7960 driver circuit, combined with a step-down regulator, to control actuators in the form of a DC motor and a conveyor. The DC motor serves as a mechanical drive, while the conveyor is responsible for transporting and disposing of chicken manure to a collection container.

3.2.2. Software Design

The design at this stage involves creating system use cases and system software design, which can be seen in Figure 3.



Gambar 3. Use Case Diagram

Figure 3 illustrates the interaction between the farmer and an IoT-based chicken manure management system designed to operate automatically. The system has two main use cases: MQ2 sensor control and RTC control, which represent environmental condition-based and time-scheduled control mechanisms. In MQ2 sensor control, the system monitors air quality inside the coop and, when a threshold value is exceeded, automatically executes the manure removal process by activating the conveyor and DC motor. Meanwhile, RTC control enables the system to execute manure removal based on a predetermined time schedule.

3.3. Implementation

In the implementation phase, the designed system will be realized in a tangible form by integrating hardware and software according to the specifications set out in Figure 4.

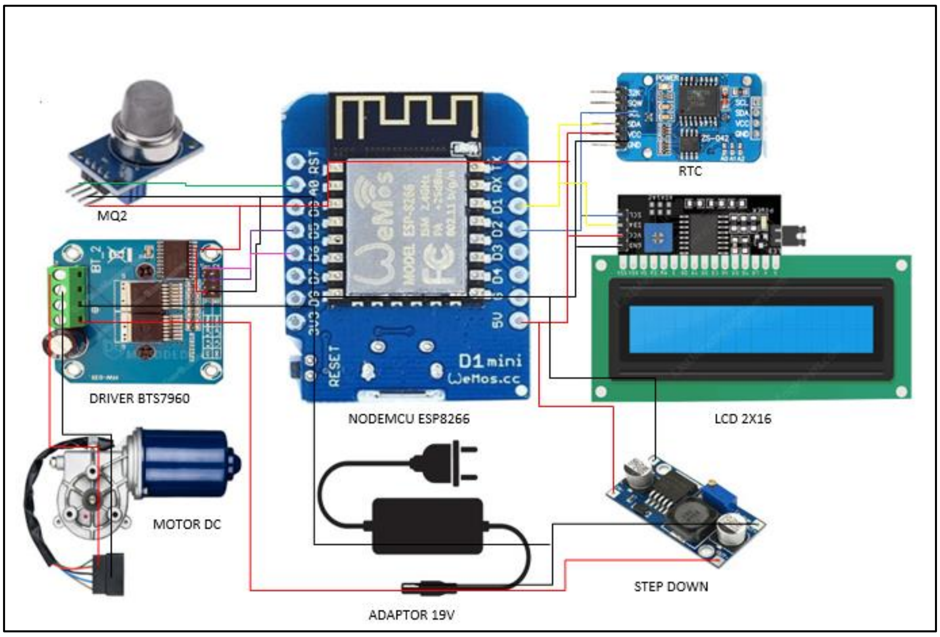


Figure 4. Tool Schematic

Figure 4 shows the hardware design of an IoT-based chicken manure management system integrated with a NodeMCU ESP8266 as the control and data processing center. This microcontroller receives input from the MQ2 sensor, which monitors air quality in the chicken coop environment, specifically the concentration of gases produced by chicken manure. Furthermore, an RTC module is connected to the NodeMCU ESP8266 to provide accurate time information, enabling the system to automatically clean the manure based on a predetermined schedule. Information regarding environmental conditions and the system's operational status is displayed in real time via an LCD module serving as a user interface.

On the actuator side, the NodeMCU ESP8266 controls the BTS7960 motor driver, which acts as a current amplifier to operate a DC motor. The DC motor drives the conveyor, the primary mechanism for discharging chicken manure into the collection container. The power supply system uses a 19V adapter as the primary source, which is then reduced in voltage through a step-down module to meet the operating requirements of the microcontroller, sensors, and other supporting modules. This configuration is designed to maintain voltage stability and operational reliability of the system, so that the overall schematic reflects the integration of sensors, scheduling systems, control units, actuators and display interfaces in one automation system that supports the implementation of smart farming efficiently and sustainably.

3.3.1. Hardware Implementation

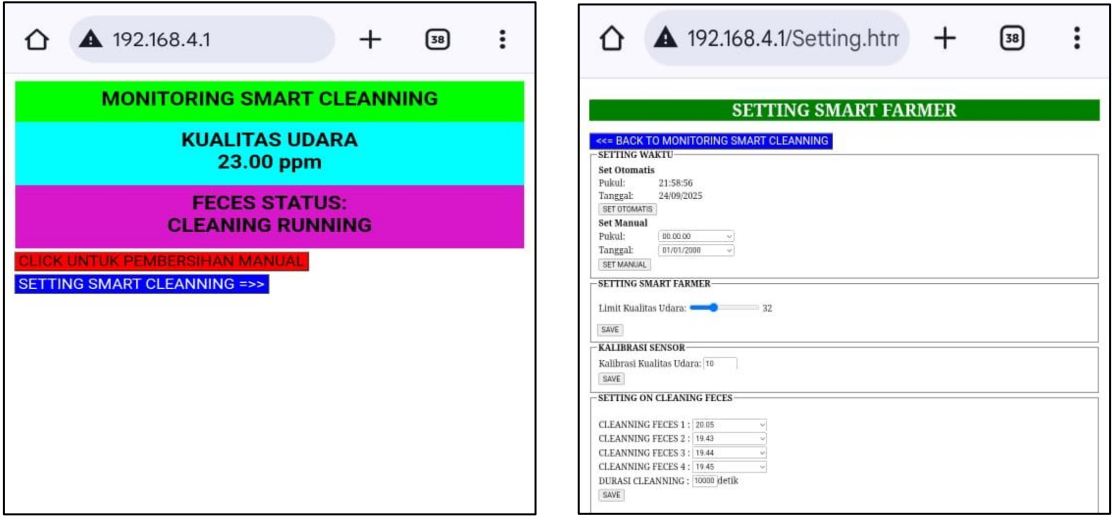
Hardware implementation is a crucial step in realizing an IoT-based smart farming system. Various physical components, such as gas sensors, microcontrollers, conveyor actuators, and DC motors, are installed and configured for optimal operation. This process includes assembling and integrating all hardware to communicate with the main control system and ensuring each component functions as designed.

Figure 5. Smart Farming Series Results

The entire set of tools in Figure 5 each has its own function. The NodeMCU ESP8266 serves as the main control center in the IoT-based smart farming system, connecting and integrating various sensors and actuators to ensure optimal coop conditions. Connected sensors, such as the MQ2 for gas monitoring, transmit real-time data to the microcontroller, which then analyzes and makes decisions based on predetermined parameters. If the sensor detects that the gas is outside the set limits, the NodeMCU activates or deactivates the conveyor and DC motor, ensuring a stable coop environment that meets the needs of the laying hens.

3.3.2. Software Implementation

The developed software is used to process data from gas sensors and RTCs, as well as control conveyor actuators and DC motors based on predetermined parameters. Through a mobile application interface, farmers can easily monitor barn conditions remotely, receive alert notifications, and change settings as needed. A screenshot of the software can be seen in Figure 6.



KUALITAS UDARA
23.00 ppm

FECES STATUS:
CLEANING RUNNING

SETTING WAKTU
Set Otomatis
Pukul: 21:58:56
Tanggal: 24/09/2025
Set Manual
Pukul: 00.00.00
Tanggal: 01/01/2000

SETTING SMART FARMER
Limit Kualitas Udara: 32

KALIBRASI SENSOR
Kalibrasi Kualitas Udara: 10

SETTING ON CLEANING FECES
CLEANNING FECES 1 : 20.05
CLEANNING FECES 2 : 19.43
CLEANNING FECES 3 : 19.44
CLEANNING FECES 4 : 19.45
DURASI CLEANNING : 10000 detik

(a) (b)

Figure 6. Software Implementation

Figure 6a shows the main system monitoring page, which displays air quality information in ppm (Parts Per Million) and the status of the dirt cleaning process. The image shows the measured air quality at 23 ppm, and the system status indicates that the cleaning process is in progress. Additionally, there is a command button for manual cleaning, accessing the settings page. Figure 6b shows the Settings page, which allows for more detailed system configuration. In this section, users can set automatic scheduling based on a specific time and date, or perform manual activation. Additionally, there are settings for air quality thresholds, sensor calibration, and parameters related to cleaning duration, allowing users to determine how long the DC motor and conveyor will operate.

3.4. Testing

Functional testing of this system was conducted to ensure that each component and module in the circuit functioned appropriately and collaborated to achieve the system's primary function [20]. The testing phase began with the DS3231 RTC module to ensure the system could read and execute the automatic waste disposal schedule at the specified time. Next, testing was performed on the MQ135 sensor to detect air quality by measuring hazardous gas levels; if the threshold value is exceeded, the system must automatically activate the disposal mechanism.

Afterward, testing continued on the ESP8266 microcontroller as the control center to verify the process of receiving input from the sensors, processing the data, and sending instructions to the driver. The BTS7960 driver was tested to ensure its ability to control current to the DC motor, while the DC motor and conveyor were tested to check mechanical movement within the specified duration (e.g., 15 seconds). The LCD display was tested to verify the real-time display of sensor information and system status. Table 2 shows the results of the system functionality testing.

Table 2. System Functionality Test Results

No	Tools	Test Scenario	Expected Result	Result	Status
1	RTC DS3231	Running the system on a predetermined waste disposal schedule	The system executes the disposal command exactly at the scheduled time.	The system executes according to time	Pass
2	Sensor MQ2	Measures air quality under varying conditions (normal & hazardous gases).	The sensor detects gas levels; if the level exceeds a threshold, the system automatically activates the exhaust mechanism.	The sensor reads the value and the exhaust mechanism is activated when the threshold is exceeded.	Pass
3	ESP8266	Receives input from the RTC & MQ2, processes the data, and then sends instructions to the driver.	ESP8266 processes the data correctly and sends control signals according to logic.	Instructions are sent to the driver according to sensor input and the schedule.	Pass
4	Driver BTS7960	Receives control signals from the ESP8266 and regulates the current to the DC motor.	The driver responds to the signals by regulating the current to the motor without error.	The controlled motor current is stable.	Pass
5	Motor DC + Conveyor	The system starts the motor according to the duration (±15 seconds) for disposal.	The motor and conveyor move according to the command with the correct duration.	The motor moves for ±15 seconds according to the setting.	Pass
6	LCD Display	Displays sensor data (MQ2), discharge status, and timing information.	Information is displayed in real time, accurate, and easy to read.	Information is displayed clearly and according to the sensor.	Pass

The results of the functional testing of the IoT-based chicken manure management system indicate that all key components function as designed. The first test was conducted on the RTC DS3231, which plays a role in the automatic scheduling of the manure disposal process. The results showed that the system was able to execute commands precisely at the specified time without any significant delays. Next, the MQ2 sensor was tested by providing a variety of air quality conditions, both normal and with gas levels exceeding the threshold. The sensor successfully detected changes in gas concentration, and when the threshold value was exceeded, the system automatically activated the disposal mechanism as designed.

Testing continued on the ESP8266 microcontroller as the system control center. The ESP8266 was proven capable of receiving input from the RTC and MQ2 sensors, then processing the data and sending instructions to the driver correctly. In the next stage, the BTS7960 driver was tested to ensure its ability to regulate current to the actuator where the test results showed that the driver could channel current to the DC motor stably. The DC motor and conveyor were then tested to evaluate mechanical performance. The motor was able to operate for a specified duration of approximately 15 seconds and drove the conveyor to transport chicken manure to the collection container. Finally, the LCD display was tested to display system information, including sensor data, disposal status, and time information. The test results showed that the LCD could display data in real-time, clearly and accurately. Overall, all system components were declared to function properly, this is in accordance with what was reported by Lengkong et al. [20].

4. CONCLUSION

This research successfully developed a prototype of an IoT-based multi-level chicken manure management system that integrates the DS3231 RTC module, MQ2 sensor, ESP8266 microcontroller, BTS7960 driver, DC motor, conveyor, and LCD display. The results of functional testing showed that all components function according to their roles and are able to collaborate optimally in supporting the automation of manure disposal. The RTC is able to run automatic scheduling according to the specified time, the MQ2 sensor detects air quality well, the ESP8266 processes data and sends instructions precisely, the BTS7960 driver supplies a stable current, the DC motor and conveyor operate according to the set duration, and the LCD displays information in real-time accurately. In addition, the results of this research open up opportunities for further development, both in terms of integrating additional sensors, implementing machine learning algorithms for environmental data analysis, and utilizing blockchain technology to increase transparency and data security in modern livestock management systems.

5. ACKNOWLEDGMENT

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