DEVELOPMENT OF IOT-BASED DECISION SUPPORT SYSTEM FOR ENVIRONMENTAL MONITORING IN POULTRY HOUSES

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ABSTRACT: *As an essential commodity, poultry contributes to the billion-peso livestock industry in the Philippines. Environmental monitoring is crucial in the overall production of poultry as there are limitations to parameters. Beyond these limits can harm and cause deaths to the poultry. Various technologies are deployed to help address the environmental monitoring challenges in poultry houses. However, developed systems are lacking in monitoring critical environmental factors in harmful gas, microclimatic, and air quality categories. Covering these key categories allows poultry farmers or caretakers to have timely intervention and maintain an optimal poultry house environment. This study presents an IoT-based system capable of monitoring various parameters from these categories through wired and wireless sensor modules connected over a network. The wireless sensor module comprises a LoRa (Long Range) module and multiple RS485-type sensors that monitor ammonia, carbon dioxide, hydrogen sulfide, temperature, humidity, wind velocity, and particulate matter 10 and 2.5. The wired sensor module comprises the same set of sensors but is connected (wired) to an ESP32 microcontroller. Sensed signals are wirelessly sent to a database, and a web application displays data visualization for a decision support mechanism. The system is deployed in an actual poultry farm.*

Keywords: air quality, harmful gas, microclimatic, module, particulate matter, sensor, web application

1. INTRODUCTION

Poultry is one of the most consumed commodities in the Philippines. As the population increases, the demand for more food supplies also increases, making livestock production a billion-peso industry in the country [1]. Increasing the number of livestock and poultry housing is necessary to cope with this demand, making it more challenging to monitor poultry production status because traditional monitoring practices require more workforces and are complicated [2]. Innovative poultry systems are developed to address this gap, including precision livestock farming (PLF) technologies, wireless/wired sensor networks (WSN), and decision support systems (DSS) [3]. Environmental monitoring of crucial parameters, such as temperature, humidity, and ammonia (NH_3) levels, in poultry houses is necessary because these parameters directly impact poultry's overall welfare and production. Therefore, it is essential to monitor these parameters accurately and reliably [4, 5].

Poultry challenges that need to be solved remain, and multi-scale monitoring of the poultry house environment is no exception [6]. Critical environmental factors can be grouped into three categories as: harmful gas [7], microclimatic [2], [8–12], and air quality [13, 14]. Harmful gases include NH_3, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and hydrogen sulfide (H2S). The emission of these gases in poultry houses could lead to a significant loss in production [7]. Microclimatic, such as high temperature, negatively affects poultry health and production. At the same time, humidity affects poultry weight and quality [9]. Another microclimatic is wind velocity, a key parameter affecting poultry productivity [10]. Particulate matter (PM), as an air quality parameter, is considered an environmental problem in poultry farming as it can absorb various pollutants such as heavy metal ions, pathogenic microorganisms, and even NH3 [13]. Particulate matter PM10 and PM2.5 in poultry houses tend to become 100 times higher than the required public health and welfare limit. Beyond these limits will impair the poultry and caretakers' liver, kidney, and respiratory systems [14].

Several studies [2, 8, 9, 15–18] developed monitoring systems for relevant environmental factors using the Internet of Things (IoT). However, these systems are limited regarding the monitored parameters and do not cover the relevant categories. With this research gap, this study aimed to develop an IoT-based system that enables real-time monitoring of critical environmental factors under the three categories to help improve poultry health, welfare, and productivity as a decision-support system. Farmers can use the system to provide timely interventions and necessary adjustments and maintain desired conditions for the poultry houses.

Specifically, the study aimed to develop sensor modules capable of reading levels of NH3, CO_2, H_2S, temperature, humidity, wind velocity, and particulate matter 10 and 2.5 and design and implement a web application for real-time monitoring of these environmental factors. The system does not include actuating and control mechanisms due to the different structural characteristics of poultry houses. This approach makes the system easily deployable and extendable to other poultry houses.

2. MATERIALS AND METHODS

The study used agile, a system development methodology (SDM) consisting of requirements, design, development, testing, and deployment phases. This methodology is adopted because it is the better approach in terms of quality assurance [19] and increases a project's productivity [20].

2.1 Requirements

The authors collaboratively identified and defined the requirements for the system with stakeholders such as poultry farmers, experts in poultry farming, and technical specialists. The main focus of this phase was to identify the specific environmental factors to be considered in monitoring and validating what is in the literature. Table 1 shows the environmental factors considered under the three categories. Hardware, software, and other requirements and specifications were also established in this phase.

Table 1. Environmental factors considered for monitoring

Harmful Gas	Microclimatic	Air Quality
NH_3	Temperature	PM10
CO_2	Humidity	PM2.5
H2S	Wind Velocity	

2.2. Design

The next phase included designing the IoT system's architecture, selecting appropriate and available sensors in the market, defining data communication protocols, and designing the database and user interface for the web application. A sensor module is designed to integrate multiple RS485-type sensors to measure each environmental parameter. The RS485-type sensors are used as adopted from the study of [21]. Two types of sensor modules were developed to differentiate performance: wireless and wired. Two of each type would be installed in a poultry house's key areas (AREA 1 and 2). A 12-volt centralized power supply powers these sensor modules. Two wireless communication modules are used for each sensor module type: LoRa module [22] (wireless) and ESP32 microcontroller [23] (wired) for comparison purposes.

NH3, CO2, H2S, and PM sensors (Gas and PM) were grouped in a casing for the wireless sensor modules. Another casing grouped the wind velocity and temperature/humidity sensors (microclimatic). The two casings are connected to an RS485 to UART converter since the sensors are incompatible with the communication module used, the LoRa module. The converter is then connected to the communication module (LoRa) with a buck converter to power the module with the 12-volt supply down to 5 volts. Each wireless sensor module is connected to a sink node LoRa module as the central point for data aggregation. LoRa modules are used because it has standardized communication protocols and can transmit wireless signals across long distances while penetrating indoor environments [24]. The design of the two wireless sensor modules (wireless sensor network) is illustrated in Figure 1.

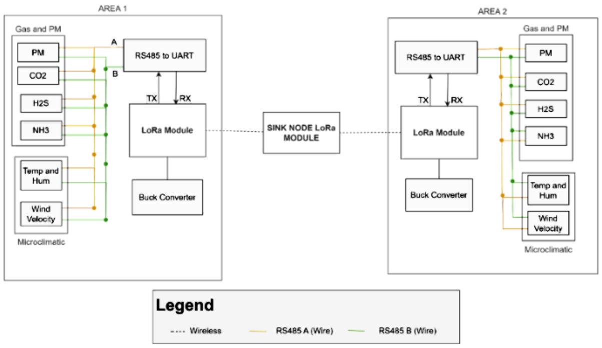


Figure 1. Design of the wireless sensor modules

The same sensor groupings in casings are designed for the wired sensor modules. In contrast, a module has no RS485 to UART converter and LoRa module. Instead, the modules are directly connected (wired) to a communication module comprising an RS485 to UART converter and an ESP32 microcontroller with a buck converter. Because of its low-cost but broad deployment capabilities and support for wireless protocols [25], the ESP32 microcontroller is chosen. Shown in Figure 2 is the design of the two wired sensor modules (wired sensor network).

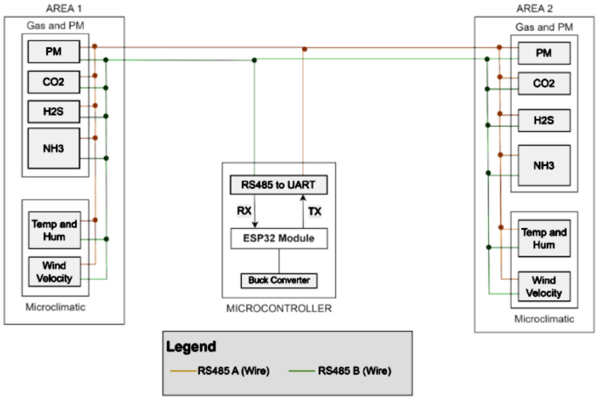


Figure 2. Design of the wired sensor modules (wired sensor network)

Real-time monitoring is the system's goal through data visualization via the web application. From the sink node LoRa module of the wireless sensor network and the ESP32 microcontroller module of the wired sensor network, sensed signals are passed onto a database through the Wireless Local Area Network (WLAN). MySQL is used in the database because of its relational capabilities [26]. Blazor server, through Visual Studio 2022 IDE, is used in web development. Blazor is a full-stack c# web framework that can manage client and server sides without using different frameworks [27]. The data from the database can then be fetched into the web application for data visualization.

2.3. Development

The system was built and implemented using sprint cycles to integrate sensors and communication modules and establish connectivity. Each communication module sends the sensor data to a wireless router connected to a database for web data processing, as shown in Figure 3.

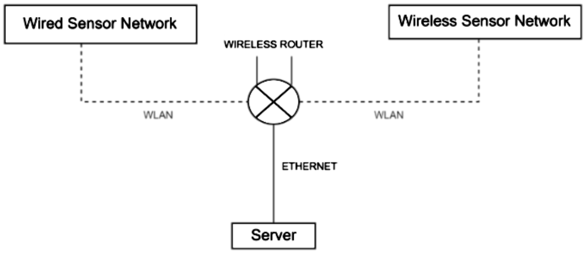


Figure 3. Two sensor networks connected to a server via WLAN

2.4. Testing

Testing is an essential part of the agile methodology [28]. Following the methodology, the design, development, and testing phases are iterative. Before proceeding to the deployment phase (last phase), a performance test was conducted to ensure the accuracy and reliability of the system. The authors conducted performance tests that met the specified requirements for the system's hardware, software, and communication aspects. Requirements of each aspect were determined in the requirements phase of the methodology. Test cases validated sensor readings, data accuracy, and real-time monitoring capabilities. The overall system performance was tested based on the requirements shown in Table 2.

Table 2. Performance test requirements

Aspect	Component	Requirement
Hardware	harmful gas sensors	The sensors must read levels of NH3, CO2, H2S, temperature, humidity, wind velocity, PM10, and PM2.
	microclimate sensors	
	air quality sensors	
	communication modules	All communication modules must receive and read sensor signals and forward them wirelessly to the database.
Software	database	The database must receive the sensor data from the communication modules and have a table to store each sensor value.
	visualization	The web application must display and visualize sensed signals accordingly.
Communication	calibration	Sensed signals visualized in the web application are calibrated to the actual environmental values.
	timing	Sensed signals visualized in the web application must be real-time based on the specified interval.

2.2. Deployment

The system was planned to be deployed in two poultry houses, as shown in Figure 4-the wireless sensor network in Building A and the wired sensor network in Building B. A sensor module is strategically planned to be installed end-to-end on each poultry house's designated areas—one near the building's fans (AREA 1) and the other near the cooling pads (AREA 2).

3. RESULTS AND DISCUSSION

The developed system can monitor NH3, CO2, H2S, temperature, humidity, wind velocity, PM10, and PM2.5 levels. These environmental parameters are categorized into harmful gas, microclimatic, and air quality. Each parameter has a corresponding RS485-type sensor for reading signals into a LoRa module (wireless sensor network) and ESP32 microcontroller (wired sensor network). The sensed signals are sent to a database via WLAN. Sensed signals are then visualized for a decision support mechanism in the web application.

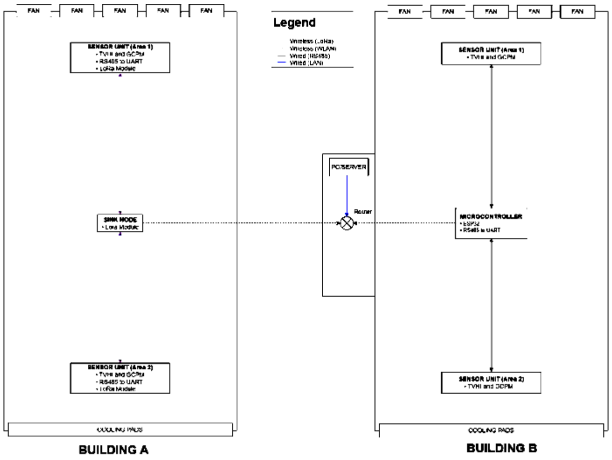


Figure 4. System deployment plan

3.1. Sensor Modules

The sensed environmental parameter signals of the RS485-type sensors were passed on to their respective communication module as sensor values. The harmful gas and air quality sensors were grouped into a single case, as shown in Figure 5(a), along with the LoRa module and RS485 to UART converter for the wireless sensor module. The microclimatic sensors are likewise grouped in another case shown in Figure 5(b). These two interconnected casings make up a single sensor module of the system.


(a) (b)

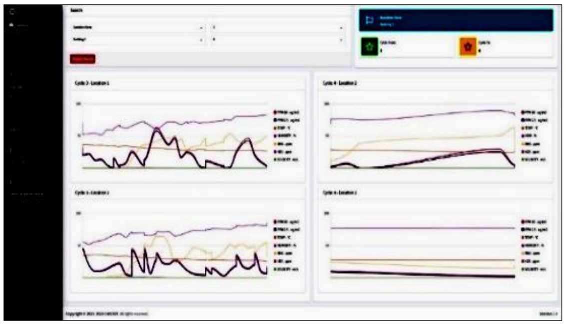
Figure 5. Sensor casings for (a) harmful gas and air quality and (b) microclimatic

Each RS485-type sensor is factory-calibrated but was validated using testing equipment. The study developed four sensor modules (two wirelesses and two wired). Each sensor could pass a signal through its respective communication module.

3.2. Web Application

The sink node LoRa (wireless) and ESP32 microcontroller (wired) communication modules could receive and read signals from the environmental RS485-type sensors and process the signals for transmission to the database over a WLAN. The database could receive the signals from each communication module wirelessly. Each sensor has a corresponding column and sensed signals are recorded at specified intervals. The web application can display all sensed environmental parameters through various visualizations. Figure 6(a) displays each sensed parameter through donut charts for the real-time sensor reading. Donut chart visualization provides better data intensity. Figure 6(b) used a spline chart to show the current and historical values and how values change at time intervals.

(a)



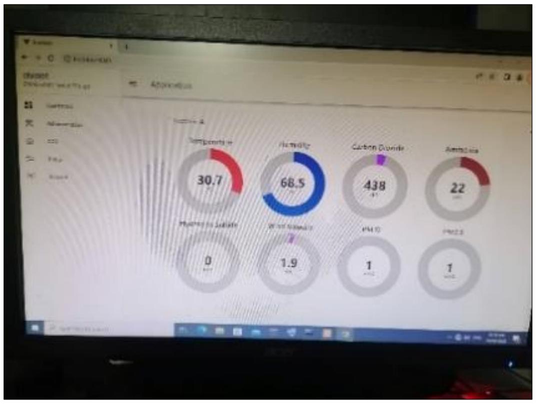
(b)

Figure 6. Web application interface visualizing the (a) real-time value of environmental parameters using a donut chart and (b) recorded values of environmental parameters using a line graph

3.3. System Deployment and Validation

A particular farm in the Davao region adopted the system in two poultry houses, Building A for the wireless sensor network and Building B for the wired sensor network. The system is deployed according to the deployment plan. Figures 7(a) and 7(b) show an installed sensor module (harmful gas and air quality) at one end of a poultry house and the web application.

(a)



(b)

Figure 7. Deployed (a) sensor module and (b) web application

The information displayed in the visualizations of the web application was validated using the testing instrument for each environmental parameter. The tests are conducted for 20 minutes by recording a sensor value every minute, getting the average, and comparing it to the test instrument's current reading. The test time was limited to avoid causing stress to the poultry. The average reading for each sensor module varies between buildings (A/B) and module type (wireless/wired). However, it does not deviate too far from the test instrument's readings. Table 3 shows the summary of the test results based on observed differences.

Table 3. Validation summary based on the observed difference between the average values from 20 readings against test instrument reading

Building A: Wireless Sensor Network			
Area	*Parameter*	*Observed Difference*	**Unit**
1	NH3	00.00	ppm
	CO2	48.00	
	HS2	00.00	
	PM10	02.60	ug/m^3
	PM2.5	02.00	
	Temperature	01.22	Celsius
	Humidity	08.58	%
	Velocity	00.00	m/s
2	NH3	01.00	ppm
	CO2	27.80	
	HS2	00.00	
	PM10	01.60	ug/m^3
	PM2.5	02.40	
	Temperature	00.92	Celsius
	Humidity	02.42	%
	Velocity	00.00	m/s
Building B: Wired Sensor Network			
Area	*Parameter*	*Observed Difference*	*Unit*
1	NH3	00.00	ppm
	CO2	188.80	
	HS2	00.00	
	PM10	03.00	ug/m^3
	PM2.5	02.40	
	Temperature	00.22	Celsius
	Humidity	14.84	%

	Velocity	00.00	m/s
2	NH3	03.00	ppm
	CO2	32.00	
	HS2	0.00	
	PM10	03.20	ug/m^3
	PM2.5	04.80	
	Temperature	02.74	Celsius
	Humidity	14.84	%
	Velocity	00.00	m/s

4. CONCLUSION

The IoT-based decision support system for environmental monitoring was able to detect critical parameters categorized as harmful gas (NH_3, CO_2, H_2S), microclimatic (temperature, humidity, wind velocity), and air quality (PM10, PM2.5). Wireless and wired sensor modules were developed to detect these parameters. Sensed signals were passed on to communication modules for processing and consequently passed on to the database server using WLAN. Monitored parameters were successfully visualized through the web application as the decision support mechanism. Both wired and wireless sensor networks performed well in accuracy with no significant difference and a little deviation from the actual parameter values. The system is deployed in two poultry houses on a farm in the Davao region, Philippines. Poultry farmers can use the system as the decision support system concerning environmental anomalies.

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