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Automation and Control of an Experimental Ventilation System to be Implemented in Livestock Farms Using IoT Technology

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Abstract: The growing development of process automation in livestock management has driven many farmers to implement new technologies that optimize operational efficiency. Specifically, the automation of ventilation systems has stood out for its vital importance in livestock farms as well as energy savings. In this work, the automation and control of an experimental ventilation system to be implemented in a livestock farm using Internet of Things technology are presented. It can intelligently collect and monitor the environmental conditions in the livestock farm in real time. The solution is designed with the possibility of being applied in different livestock farms. The system drives the installed actuators and is accessible to the user for monitoring their operations and problems. This proposal presents outstanding details such as an intelligent activation system, energy savings, and ease of use.

Keywords: **Ventilation automation, smart ventilation systems, IoT technology, farm ventilation**

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1. Introduction

Every year, environmental demands regarding greenhouse gas (GHG) emissions increase, and animal welfare regulations are modified, expanded, and become more stringent. This requires deeper research into all systems that affect the quality of life of animals living on a farm (Shields & Orme-Evans, 2015). Thus, an adequate balance and monitoring of gas emissions, as well as control of air extraction systems in livestock facilities, would allow for greater comfort for animals and greater efficiency in ventilation on farms (Yan et al., 2024).

Due to the wide range of real-time monitoring applications, both commercial systems and open-source prototypes made of low-cost or in-house sensors connected and set up with wireless communication networks have been developed. These systems enable real-time data collection and the creation of processing and visualization platforms that make it easier to interpret the data (Botero-Valencia et al., 2022). Through the intelligent linking of numerous physical devices, the Internet of Things (IoT) is enabling new forms of communication between people and between things, as well as between things themselves. This allows for the exchange of data for monitoring and controlling the devices from any location in the world with an internet connection (Al-Fuqaha et al., 2015).

Nowadays, modern technology allows for the inclusion of intelligent monitoring systems in livestock breeding and production, which are crucial for their optimal development. The purpose of these is to be able to monitor variables such as temperature, humidity, and gases in real time (Neethirajan, 2020). An IoT platform helps monitor activities, allowing for decision-making and creating an environment conducive to the proper growth and management of livestock (Zhang et al., 2021).

Specifically, automated air control systems are an advanced technology that allows industries to manage and control the air quality in their environment. These systems use a combination of sensors, controllers, and intelligent software to make decisions automatically (Lakhiar et al., 2018). Their ability to measure air quality, humidity, temperature, and the presence of particles is especially useful in industrial environments that can be difficult for workers due to environmental factors. Among the advantages that these systems offer is the improvement of the health, comfort, and safety of workers. Automating these functions also reduces energy costs and increases the efficiency of production processes. Furthermore, these systems can be customized to adapt to the specific needs of each industry, which is essential for the proper development of the health, environmental, and comfort process (Idrees & Zheng, 2020; Dounis & Caraiscos, 2009).

Environmental control through ventilation systems in livestock farms is essential to achieve ideal conditions of comfort for the animals, which in turn will have a direct impact on the production and technical results of the farms (Fournel et al., 2017). When measuring emissions on farms, airflow and pollutant measurements are difficult to apply in practice (Larios et al., 2016). Specifically, this is very difficult to apply on farms with both forced and natural ventilation due to variation in pollutant concentration and air velocity at the vent level (De Vogeleer et al., 2018; Mostafa et al., 2017). The restricted number of measurement locations typically does not accurately reflect the velocity and concentration distributions in the vents; therefore, simply calculating the product of the differential pollutant concentration and airflow rate may produce erroneous findings (Park et al., 2018).

Farms are typically spread across agricultural areas at a considerable distance from each other, and the farmer needs to be physically monitoring and controlling the status of the animals (Monteiro et al., 2021). Automation helps everyday and industrial activities in the process of digital transformation. Today, companies are facing major revolutionary changes, and it is essential to manage, modify, and adapt not only the IT infrastructure, but also all company processes (Kraus et al., 2022). If you simplify the implementation of changes with automation, you will have the time and energy to focus on generating innovations. The goal of automated processes is to carry out activities more quickly, which allows staff to focus on solving the most important problems, then incorporate the solution into the work routine and even identify whether it can be automated (Coombs et al., 2020; Filippi et al., 2023).

Pervasive monitoring, provided through wireless sensor system innovations, is dispersed in numerous areas of modern life. This enables environmental parameters to be detected, interpreted, evaluated, and deduced from natural resources (Fascista, 2022). The increasing number of Internet-connected devices has led to the escalation of the technological revolution in the IoT. The seamless integration of sensors and actuators enables IoT technologies to be one of the most important technologies in modern life (Mahbub et al., 2020). Due to the development of sensor networks, heating, ventilation, and air conditioning (HVAC) systems based on building automation systems (BAS) have gradually replaced traditional HVAC to improve indoor thermal comfort and decrease energy

consumption (Zhao et al., 2023). HVAC systems constitute a significant portion of energy use and carbon emissions of buildings. The quality of design directly affects the energy-saving and carbon-reducing effects of HVAC systems. A high-quality HVAC system design requires the use of automatic and intelligent methods, since traditional HVAC system design is based on experience, is repetitive, time-consuming and difficult to optimize (Krajčík et al., 2023). The multiple benefits obtained from the installation of such an automated system must be considered. The electronic implements managed by this system will only be used when necessary, that is, when someone is in the perimeter established for the activation of the sensors, which means energy savings (Viani et al., 2013).

The implementation of IoT technologies related to monitoring and ventilation systems in farms is the subject of recent research due to the massification of automated systems in rural areas as well as a pressing need for advanced air quality monitoring systems to manage and mitigate these emissions effectively. Choukidar and Dawander (2017) developed a smart management system for a poultry farm. It was identified that many activities that require a lot of human labor can be automated, such as monitoring and control of environmental conditions by ventilation, cooling, and heating. The proposed smart monitoring system can reduce cost, time, and labor, as it is also very user-friendly for farmers. Popa et al. (2022) presented a case study of air pollutant emissions and their correlation with farm management and animal welfare by using IoT technology. The findings demonstrate the existence of interactions between the microclimate and pollution emissions, and they can offer a model for farm operations that the farmer can control based on the measurement results. Jeong et al. (2023) proposed a digital twin framework for pig houses to ensure optimal performance and comfortable feeding conditions for the livestock sector. It was identified that using optimal control of the HVAC system is more energy efficient than using the traditional control method. Arulmozhi et al. (2024) developed a low-cost air quality monitoring system for swine buildings. The system is set up with a central web server that makes data available online and visualizes it in real time. The authors plan to improve the usability and functionality of the system by adding more features, like ventilator fan controls. Liu et al. (2024) implemented a smart platform for monitoring the environment of a poultry farm facility. Data statistics and alert modules efficiently track system state, enabling quick program response. Features that have been demonstrated include profit-loss analysis, psychrometric chart alerts, and sound identification. Fu et al. (2022) developed a remote monitoring system for livestock environmental information by using IoT technology. After application on a dairy farm, the reaction time was less than 10 s, and the control instructions were precise and real-time. The technology offered technical assistance and robust data for precise animal production and management.

Gaseous emissions from livestock farms have a significant impact on the quality of indoor air on farms and in their surroundings. On farms, the main emissions into the atmosphere are suspended particles, harmful gases, and unpleasant odors. The first two have a negative impact on the health of animals and farmers. Harmful gases such as ammonia and methane can also disperse over greater distances and contribute to eutrophication and acidification of ecosystems. Odorous substances are also dispersed significantly in the farm environment, causing sensory discomfort that can cause significant socio-economic impacts in areas with high livestock density (Spoolder et al., 2011).

Therefore, this study proposes an experimental ventilation system that can be installed in livestock farms and provides real-time temperature and gas concentration data by using IoT technology to automate the system. Its remote-control capability enables us to keep livestock farms under control. Implementing the controller on livestock farms allows us not only to maintain adequate working environments but also to optimize resources, both in energy consumption and in man-hours of exposure to various gases, such as ammonia and methane, and to high temperatures. The ventilation system can be monitored and controlled in real time from any computer or mobile device, allowing us to spend less time exposed since the controller keeps us informed in real time about the change in variables and allows us to control and activate the actuators remotely.

2. Methodology

The methodology applied for the controller device is based on the programming of the ESP32 microcontroller, where the measurement parameters that are taken by the sensors and will determine the actuation of the ventilation system are established. The controller is based on an integrated system for collecting data from the sensors and the ESP32 integrated controller with Wi-Fi connectivity. The integrated control system together with the actuators can be powered by a battery or solar energy,

or connected to the domestic electrical network. The power supply and data processing response are shown in Figure 1.

The controller will receive information from the ventilation system to monitor whether it is working properly, check the airflow, and maintain the gas concentration and temperature within certain parameters. The information captured by the controller is transmitted in real time to the network so that it can be viewed using a mobile application or computers. The device is comprised of an audible alarm, a light alarm, an ESP32 programmable controller, temperature sensors, ammonia sensors, methane sensors, air inlets, and extractors.

The controller, through its programming, allows the autonomous operation of the ventilation system. It also has the capacity to monitor, record, and save the database of sensor readings and is monitored in real time from the IoT Cloud Remote application, from where we can activate and deactivate the actuators. The temperature, ammonia, and methane sensors are responsible for capturing the readings of variables that are frequently found within the ventilation system, since the sensors can be used in environments with the presence of gases and temperatures that affect the health of people and animals within the environment of livestock farms. To calibrate the sensors, several measurements were taken under controlled conditions as shown in Figure 2.

Known values are taken and validated by thermographic equipment as shown in Figure 3.

A calibration curve is generated from the data obtained, using linear regression techniques to determine the equation that best fits the experimental data. This method is useful for sensors whose measurements vary in a complex way, such as the gas sensors used. The obtained equation is implemented in the ESP32 controller code to correct the sensor readings in real time, as shown in Figure 4.

As can be seen in Figure 5, after a programmed time, the sound and light alarms are automatically activated when records are found that exceed the permissible parameters. Then the air extractors are activated until the values are acceptable, at which point the air extractors are activated. Alarms and exhaust fans will be deactivated automatically. This maintains the room with acceptable values of temperature and concentration of ammonia and methane.

The components that comprise the controller device are listed in Table 1.

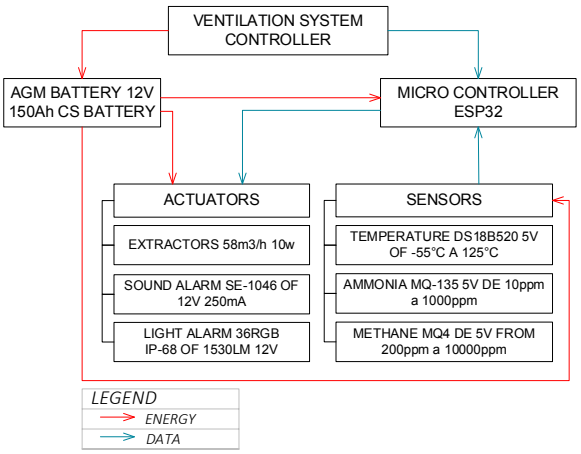


Figure 1. Schematic diagram of the electrical system and instrumentation of the control device.

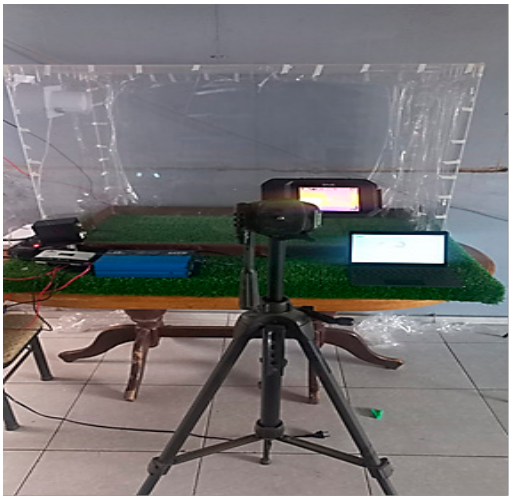


Figure 2. Encapsulation to generate a controlled environment.



Figure 3. Taking measurements with a Flir C2 thermal imaging camera.



Figure 4. Controller measurement for sensor calibration.

Table 1. Particle size and power consumption.

Elements	Detail	
	Function	Amount
ESP32 Microcontroller	Controller	1
2CH relay module	Link	1
MQ137 Sensor	Ammonia	1
DHT 22 Sensor	Temperature	1
14.1” LCD screen	Screen	1
MQ4 Sensor	Methane	1
Audible alarm	Alarm	1
Light alarm	Alarm	1

We can identify in Figure 6 the elements that make up the controller that will carry out the automation of the ventilation system.

The ventilation system controller device for automation of the system implemented for farms using IoT technology is characterized in that it comprises:

- A frame (8) responsible for supporting and containing all the components of the device and allowing the correct connection and power supply of each component.
- An ESP32 microcontroller (4) located inside the frame (8), responsible for receiving information from the ventilation system.
- A temperature sensor (1) located on the side of the frame (8), responsible for collecting temperature data inside the enclosure.
- An ammonia sensor (2) located on the side of the frame (8), responsible for collecting the ammonia level inside the enclosure.
- A methane sensor (3) located on the side of the frame (8) responsible for collecting the methane level inside the enclosure.

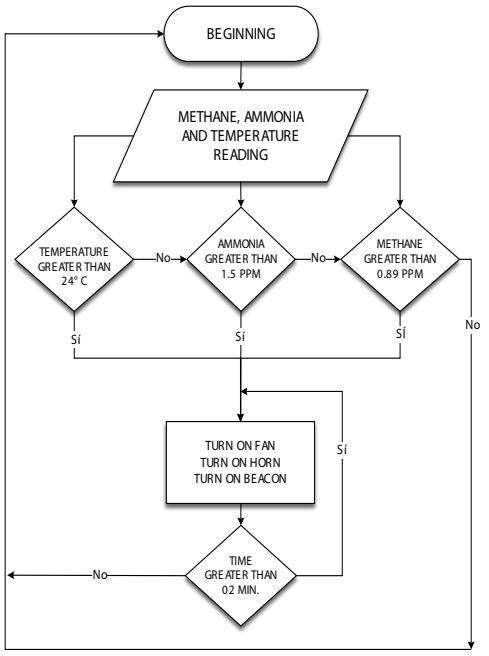


Figure 5. Flow chart of the operation of the control device.

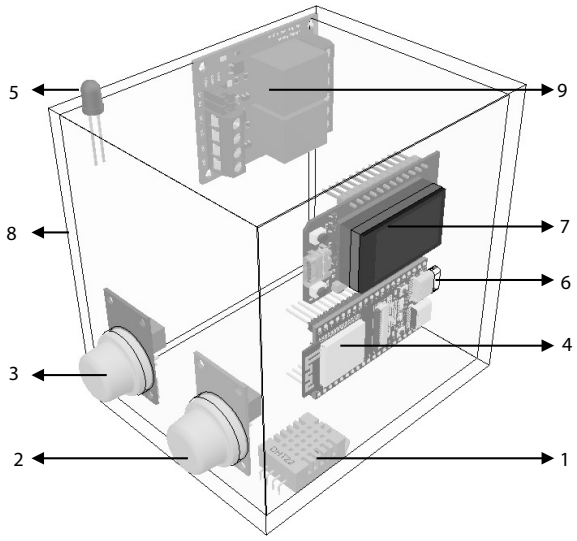


Figure 6. Controller device elements.

1. Temperature sensor
2. Ammonia sensor
3. Methane sensor
4. ESP32 microcontroller
5. Sound–light alarm
6. Power port
7. Screen
8. Frame
9. 2CH relay module

- An audible–luminous alarm (5) located in the upper part of the frame (8).
- A power port (6) responsible for connecting and charging the device.
- A screen (7) responsible for showing the status of the venue in real time.
- A 2CH Relay module (9) responsible for ensuring the correct power supply to the audible–light alarm (5)

3. Results

Three variables were used to evaluate temperature, methane concentration, and ammonia concentration. The sensors were installed in the ESP32 controller to monitor and automate an experimental ventilation system, in which the behavior of the control and monitoring system could be recorded through the IoT Remote mobile application, where data transmission is done from the sensors to the cloud through the MQTT (Message Queuing Telemetry Transport) protocol. It is a lightweight protocol based on the publish/ subscribe model and uses TCP/IP to ensure reliable message delivery. Thanks to its low resource consumption, MQTT is ideal for research, since we make use of devices with power limitations and networks with reduced bandwidth. We verify the communication in Figure 7, where we can see that the monitoring of the variables is in real time and, at the same time, their behavior can be observed over time. The IoT Cloud Remote app allows you to store up to 1 year of data in the developer version, from which you can download the stored data and review the measurement values at any time during a given period of time.

Using the programmable controller, we are able to operate the ventilation system autonomously, since its programming considers initially automatically activating the sound and light alerts, and then, after the programmed time, activating the air extractors, which allows us to maintain acceptable values of temperature and gas concentration within the farm. Likewise, once the permissible values have been obtained, the controller will give the order to turn off the extractors and alerts automatically.

The automated ventilation system is monitored and controlled through the controller in real time from the IoT Cloud Remote mobile application found on the Play Store mobile platform, from which we can store a database of the behavior and measurements of the sensors, and determine when to remotely control the activation of the actuators, which in this case are the air extractors.

To start with the development of the controller device, a demo was made as seen in Figure 8; then a functional

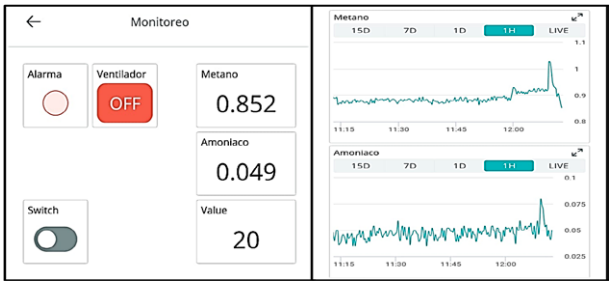


Figure 7. Measurement graph in IoT Cloud Remote.

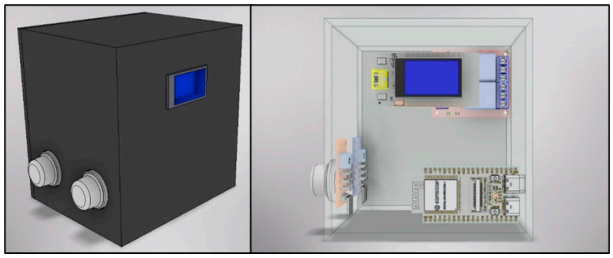


Figure 8. Demonstration of the packaging and front view of the control device.



Figure 9. Functional prototype of the controller device.

prototype was made where some programming details could be corrected with respect to the values taken by the sensors, as shown in Figure 9. Likewise, the IoT Cloud Remote platform was tested with the data sent by the experimental controller device. With all the information collected and after evaluating and adding all components such as the humidity sensor, the final product was made, resulting in the controller device for monitoring and controlling ventilation systems applied in livestock farms, as shown in Figure 10.

The variables to be considered are a starting point to be able to begin the implementation of the automation of the ventilation system, since at certain values and within the permissible parameters programmed in the controller, they will be the indicators for the activation of the system.

To perform statistical control and monitoring, the values measured by the controller can be observed in the



Figure 10. Controller device operation.

IoT Cloud Remote application, and each measured value is in a monitoring range established by the parameters indicated in Table 2, which determine the corresponding actions through the activation of the audible alarm, the light alarm, and the actuators (air extractors) to maintain a controlled environment within the farm to be monitored.

Table 2. Ventilation system monitoring parameters.

Description	Parameter	Light Alert	Sound Alert	Activation Time
Volker air extractor	≥25°C, ≥20 ppm NH_3 ≥25 ppm CH_4	Yes	Yes	3 h to 6 h
Karson air extractor	≥25°C, ≥20 ppm NH_3 ≥25 ppm CH_4	Yes	Yes	3 h to 6 h
Broan air extractor	≥25°C, ≥20 ppm NH_3 ≥25 ppm CH_4	Yes	Yes	3h to 6 h
Broan exhaust fan	≥25°C, ≥20 ppm NH_3 ≥25 ppm CH_4	Yes	Yes	3 h to 6 h
Temperature sensor	≥25°C	Yes	Yes	24 h
MQ-135 Ammonia sensor	≥20 ppm NH3	Yes	Yes	24 h
MQ-4 Methane sensor	≥25 ppm CH4	Yes	Yes	24 h
OPALUX Light alarm	≥25°C, ≥20 ppm NH_3 ≥25 ppm CH_4	Yes	Yes	24 h
OPALUX Sound alarm	≥25°C, ≥20 ppm NH_3 ≥25 ppm CH_4	Yes	Yes	24 h

We can show the implementation on a model farm where we observe extractor locations in Figure 11, considering optimal dimensions of 3 m long by 6 m wide.

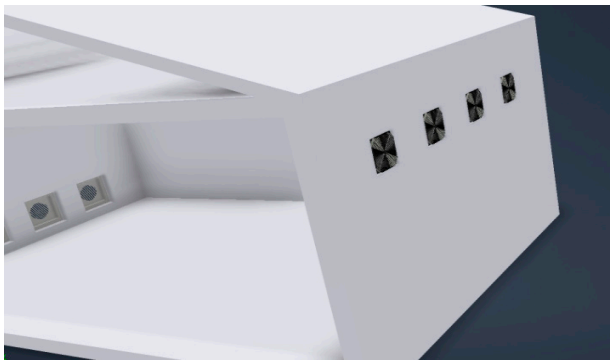


Figure 11. Location of extractors and air inlets.

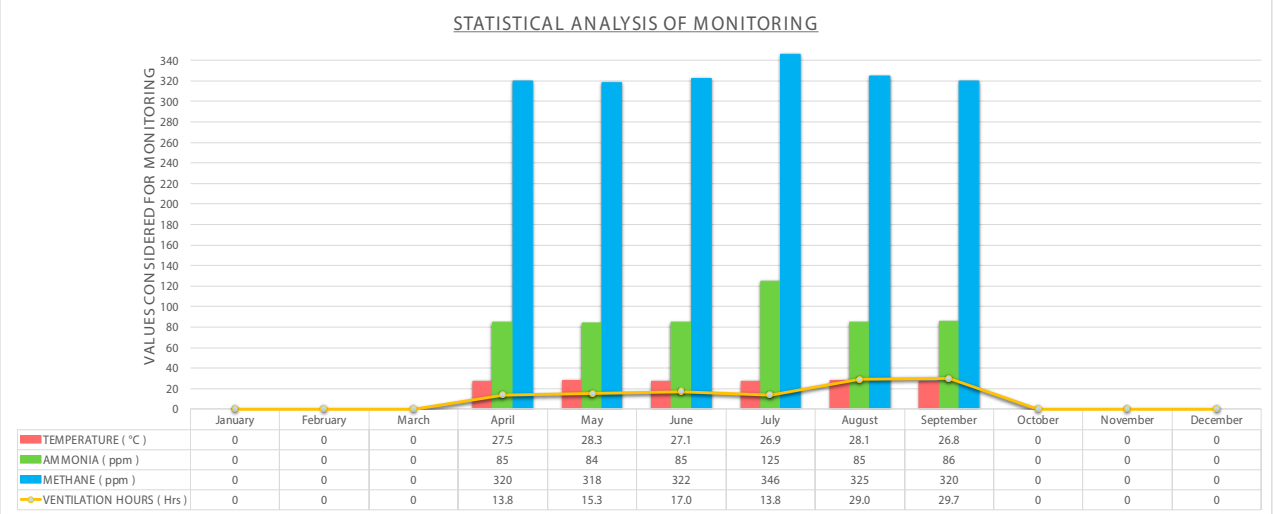
Using the programmable controller, we are able to operate the ventilation system autonomously, since its programming considers initially automatically activating the sound and light alerts, and then after the programmed time, activating the air extractors, which allows us to maintain acceptable values of temperature and gas concentration within the farm. Likewise, once the permissible values have been obtained, the controller will give the order to turn off the extractors and alerts automatically.

In Figure 12, we can observe the behavior of the measurements through a monitoring analysis graph. The automated ventilation system is monitored and controlled through the controller in real time from the IoT Cloud

Remote mobile application found on the Play Store mobile platform, from which we can store a database of the behavior and measurements of the sensors and determine when to remotely control the activation of the actuators, which in this case are the air extractors.

The operation of the controller device and the automation mode of the ventilation system using IoT technology were described. A graphic description of the ventilation system and the remote monitoring method were made using the IoT Cloud Remote application. The study also described how the operation of the ventilation system is optimized by the controller device, since the fans and alarms are activated and deactivated automatically according to the parameter values obtained from the sensor measurements.

We demonstrate that the measurement accuracy of the controller is based on calibration and comparison with standardized measurement equipment, which shows values with an error of 1% to 5%. Likewise, the latency time for gas detection within the controlled environment is approximately 130 seconds, and for temperature changes it is 95 seconds.



ITEM	MEDICIONES	MES DE INICO	MES DE TERMINO	DIAS DE MONITOREO	DIAS MUERTOS22	MOTIVO	HORAS DE VENTILACION	RESULTADO	PROBLEMAS	CONEXION IoT Remote	NOTAS
1	TEMPERATURE	Abril	September	127	25	Programming	13.8	WELL	NONE	Yeah	Ventilation balance was achieved.
2	AMMONIA	Abril	September	127	25	Programming	15.3	OPTIMUM	NONE	Yeah	The sensors must be well positioned.
3	METHANE	Abril	September	124	28	Programming	17	OPTIMUM	NONE	Yeah	The sensors must be well positioned.
4	VENTILATION HOURS	Abril	September	127	25	Modification	29	WELL	NONE	Yeah	The peaks were successfully recorded.
5	EQUIPMENT STAND BY	Abril	September	127	4	Modification	29.7	REGULAR	CONNECTIONS	No	Equipment reliability is optimal.

Figure 12. Monitoring analysis chart of parameters.

Finally, the background of other similar applications in the case of patents was analyzed, and the following comparisons were summarized in Table 3.

Conclusions

This study presented the automation and control of an experimental ventilation system to be implemented in livestock farms using IoT technology. The controller can save energy by activating the fans only when conditions demand it, thus avoiding continuous operation throughout the day. The fans are only switched on when certain specific parameters are reached, thanks to an intelligent activation system integrated into the design. This not only reduces unnecessary energy consumption but also simplifies maintenance by eliminating the need for constant operation. It allows the controller to be installed in remote locations because it does not rely solely on power grids but also on renewable energy. This is very convenient, as it allows the reduction of the carbon footprint and the implementation of renewable energy sources in remote locations. Likewise, it provides the ability to constantly monitor the status of the ventilation system remotely, as well as save data and readings to the cloud to improve system control and efficiency. This feature facilitates continuous monitoring and optimization of system performance from any location with Internet access. It has an alarm that is activated after a programmable delay, during which time, in addition to alerting the occupants of the premises, it will activate the ventilation system. The programming and learning of the controller database are based on a statistical study of the events at the site; this guarantees the correct operation of the controller and easy interpretation of data.

The proposed controller and system present some limitations. First, scalability can be compromised when the number of connected sensors and devices increases, which can generate network congestion and overload the controller, affecting the efficiency of data processing. Likewise, the controller's reliability can be affected by hardware limitations, software errors, and adverse environmental conditions that alter the accuracy of the sensors. These limitations suggest the need to develop strategies that guarantee the robustness and resilience of the system, which has already been manufactured with an acrylic encapsulation that protects against dust, humidity, and high temperatures, but not against shocks or vibrations.

Table 3. Comparison of patents with the IoT solution.

Patent	Description	Comparison
Air conditioning system, control method, controller and air conditioning unit (Luo Laiping et al., 2020)	Presents a ventilation control system for farms that incorporates IoT technology to efficiently monitor and manage ventilation in agricultural facilities. This automated system automatically adjusts ventilation based on environmental conditions and animal needs, facilitating an optimal environment on the farm.	This patent lacks key features such as energy-saving capabilities and an intelligent activation system for fans, which could result in unnecessary energy consumption.
Smart Farm Network Module Interchangeable IOT Controller Using Cloud Computing and Its Control Methods (Kim Dong-sik et al., 2021)	Describes an IoT air quality controller for air conditioning. It uses indoor/outdoor air quality measurement devices to adjust air conditioning operation based on air quality data and energy consumption.	The patent described does not have an alarm that would quickly alert building occupants of any detected problems, allowing them to take preventive or rapid response measures.
IoT-based smart ventilation device (Yundal, 2022)	Describes an intelligent ventilation system for indoor air quality management. It uses internal and external air quality sensors, together with a controller, to control building ventilation based on air conditions.	Continuous operation of fans, sensors, and other electronic components can increase system power consumption, which could result in higher operating costs and a larger environmental carbon footprint.
Automatic ventilation system using IOT sensor (Seomin, 2019)	It describes an automatic ventilation system that automatically purifies the air using an air sensor on which a Wi-Fi communication module and an air purification controller are mounted.	This patent is completely automatic and does not take into account that users may experience difficulties in monitoring and controlling the system remotely, which could affect convenience, system accessibility, and data collection.
Cascade Identification in Building Automation (Ahmed, 2019)	Describes a cascaded machine learning system for building management, which uses data to identify costs, failures, and sources of failure in building automation systems. Sequential machine learning classifiers are applied to analyze data from multiple buildings.	Cascading machine learning models can generate non-linear and complex results that are difficult to interpret and explain, which can make it difficult to identify patterns and make decisions based on the results.

Conflict of Interest

The authors have no conflict of interest to declare.

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