Design and Implementation of a Quasi Real-Time Air Quality Monitoring and Control System for Swine Production

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Abstract: Air quality management is a critical but frequently neglected factor in pig farming, with adverse effects ranging from impaired growth performance to heightened health risks and mortality. This study addresses this gap by designing and implementing a quasi-real-time air quality monitoring and control system for swine production. It introduces a quasi-real-time air quality monitoring and control system for swine production using MQ-type sensors to measure ammonia, methane, and hydrogen sulfide levels, connected to a microcontroller that relays data to a mobile application called "SwineStats". A misting pump filled with Virkon S solution was integrated to reduce gas concentrations. The system was installed in two fattening facilities, where it collected data over four weeks. Initial calibration yielded an average error of 8.54%, and trigger tests confirmed the misting system's effectiveness. Results confirmed a significant reduction in gas concentrations after misting via a Wilcoxon signed-rank test. Survey results also showed that farm owners and personnel reported reduced odor and good system responsiveness, with an overall positive response to the system. Overall, the design and implementation of the SwineStats system was a success, marking a major step towards innovation in farm management and improving biosecurity in the agriculture sector of Zamboanga City.

Key Words: air quality monitoring; pig farms; misting system; mobile application; IoT

1. INTRODUCTION

Agriculture is a crucial livelihood in the Philippines, contributing 9% to the country's gross domestic product (GDP) and employing 25% of the 49.7 million in the workforce (Montemayor, 2024). Despite its importance, there is a concerning lack of investment in maintaining the environments where livestock, particularly pigs, are raised. Swine farms face air quality issues due to the presence of harmful gases such as ammonia (NH_3), hydrogen sulfide (H_2S), carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4), which pose health risks to both workers and pigs. These gases can cause irritation, affect pig growth, and even result in death, making air quality monitoring essential (Iowa State University, n.d.).

While numerous studies have developed IoT-based systems to monitor ammonia levels in poultry farms (Revanth et al., 2021), there is a significant gap in addressing the broader range of gases in swine farms. This oversight is particularly concerning given the inherently unsanitary nature of pig farming, which can lead to various environmental and health consequences (Dorado et al., 2019). The lack of comprehensive monitoring can lead to severe consequences, as seen in Zamboanga City in September 2024, where poor biosecurity measures, including inadequate air quality management, resulted in the spread of ASF, leading to the death of many hogs. In response, veterinary field offices have strengthened biosecurity measures (Jocson, 2024).

The effects of exposing both humans and pigs to various concentrations of ammonia, methane, and hydrogen sulfide have been studied by researchers in different locations. The US Pork Center for Excellence notes a maximum recommended concentration of 11 ppm for ammonia and 10 ppm for hydrogen sulfide for swine (US Pork Center for Excellence, 2015). On the other hand, researchers also investigated the effects of various concentrations of gas on pig health, noting that pigs start experiencing problems with ammonia concentrations at around the 50-75 ppm mark and eat less at concentrations above 100 ppm, whereas concentrations above 50 ppm for hydrogen sulfide can cause intoxication, whereas concentrations below 10 ppm have no effects on pig growth (Kim et al., 2007).

Several studies have also explored using various methods to monitor environmental parameters in industrial, residential, and agricultural settings, including swine environments. A study proposed the development of an IoT-based system to monitor and control temperature, humidity, and ammonia concentrations in poultry environments (Revanth et al., 2021). This approach was also proposed for swine farms, with researchers focusing on particulate matter (Arulmozhi, 2024). Another study adopted a similar approach, prioritizing the monitoring of ammonia, carbon monoxide, and hydrocarbon concentrations in households and businesses (Karuna et al., 2023).

Other related studies and literature highlight the benefits of cleaner agricultural environments and the need to improve the monitoring of environmental parameters in the context of biosecurity. A study investigated the health and economic benefits of reducing agricultural emissions and waste, discovering that reducing agricultural emissions yields significant financial and societal benefits (Giannadaki et al., 2018). The potential harm of hog waste in the Philippines was investigated, noting severe environmental and health impacts due to inadequate waste management, with most farmers disposing of waste untreated into waterways (Dorado et al., 2019). The need to improve the monitoring of gas levels and assessment protocols was also emphasized in a study that criticized the Italian "ClassyFarm" protocol, which was deemed unsatisfactory (Buoio et al., 2023). Together, these studies highlight the need to develop systems that continuously detect and monitor the concentrations of various gases in the environment, especially in agricultural environments in the Philippines.

An IoT-based monitoring system for pig farms was proposed to address this issue. This system integrates IoT technology with sensors to detect and monitor three out of the five common gases (NH_3, H_2S, and CH_4), providing farmers with a no-contact method to ensure the health and safety of their livestock and workers. This solution aims to fill the gap in existing studies and improve the overall management of swine farming environments.

2. METHODOLOGY

2.1 Research Design

The study monitored variables such as the number of fatteners in the farm, as well as the levels of ammonia (NH_3), hydrogen sulfide (H_2S), and methane (CH_4) produced. A prototyping approach was chosen along with a repeated measures design, as the study focuses on monitoring air quality, taking measurements before and after misting. To ensure the study's feasibility, data on potential pig farm locations and their sow levels were collected during the planning phase. This approach allowed for systematic observation and analysis of air quality conditions in pig farming environments.

2.2 Conceptual Framework

Fig. 1. Conceptual Framework of the Study

Figure 1 shows the conceptual framework of the study provided in an input-process-output format. The main systems are set up at the farm station, where most of the hardware components are placed. Data coming from these sensors that monitor dangerous gases like ammonia, hydrogen sulfide, and methane is sent to the cloud by the integrated ESP32 Wi-Fi module, where it is managed, recorded, and processed. Once processed, the data is sent to the mobile application for quasi-real-time air quality monitoring. The mobile application offers a user-friendly visual display of data on air quality with accessible interfaces meant to facilitate farmers and other end-users, ensuring that the end-users are alerted in real-time, when necessary, with push notifications, while also making use of the misting components for a timely and effective response to any potential issues with air quality. With this conceptual framework in mind, the study will undergo four phases: planning, design, development and implementation.

2.2 System Planning & Design

The researchers identified two locations suitable for installation: Macrohon Integrated Farm, which has 12 fatteners and is in San Roque, and Mike's Farm, which has 17 fatteners and is in Patalon. Both farms were in Zamboanga City, and personnel from both farms, 29 in total, as well as an expert respondent from the Office of the City Veterinarian, agreed to be the respondents to the needs assessment survey, as well as the installation of the system in their farms. An end users assessment survey would also be conducted after implementation to assess their experience. Both surveys used the Likert scale as the method of assessment.

The proposed system used the ESP-32 microcontroller for its Wi-Fi capabilities and low power consumption. Other components that were also used in the system include low-cost sensors such as the MQ-4 and MQ-135 from MakersLab, and an MQ-136 manufactured by Dong, as well as a misting pump which was configured to be triggered via a 12V relay that served to be the "control" part of the air quality monitoring and control system. An inverter was also connected to the power supply to ensure that adequate power was provided to the system, and Virkon S, diluted at a 1:200 ratio as per product specifications, was chosen as the misting agent (LANXESS, n.d.).

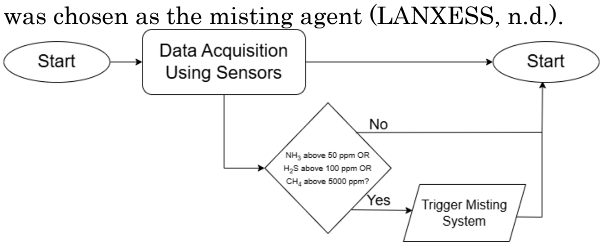


Fig. 2. Microprocessor Process Flow

Figure 2 depicts the system process flow within the ESP32 microcontroller. The MQ-4, MQ-135, and MQ-136 sensors are used to monitor ammonia (NH_3), methane (CH_4), and hydrogen sulfide (H_2S) levels within the pig farm, operating in a quasi-real-time mode to prevent the false triggering of the misting system. The misting system is set to run for 20 seconds each time it turns on. It should be noted, however, that there is no existing data regarding the relationship of misting duration and gas levels, only that misting reduces gas levels.

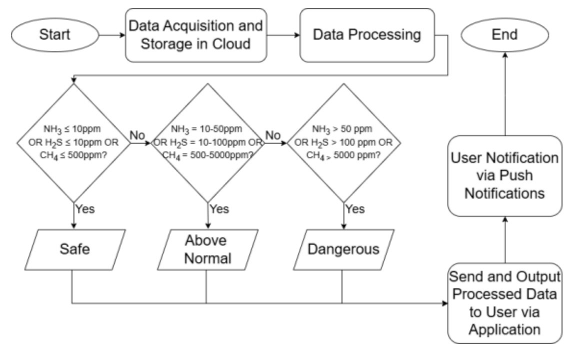


Fig. 3. Server and Application Process Flow

Figure 3 depicts the server and application process flow, detailing activities that are on the server side (back-end) and the application side (front-end). The server-side activities include data acquisition, storage, and processing, which are to be done in Firebase, whereas the application-side activities include visualizing the processed data and sending notifications to the user. The concentrations for each level were selected based on studies conducted on pig farms on dangerous gas levels (Kim et al., 2007; US Pork Center of Excellence, 2015).

Various tests and calculations were performed during the design phase to determine the appropriate power source to enable a fully solar-powered IoT air quality monitoring and control system, and calculations used the Nguyen methodology to compute power consumption by taking the average current (Bui et al., 2023). The formulas used in the Nguyen methodology are shown in the three equations below.

$$DC_{ave}\ (\%) = \frac{T_{high}}{T_{cycle}} \times 100\% \qquad \text{(Eq. 1)}$$

$$I_{ave} = I \times \frac{DC_{avg}}{100} \qquad \text{(Eq. 2)}$$

$$P = I_{ave} \times 12V \qquad \text{(Eq. 3)}$$

where:

T_{high} = Time the device is active
T_{cycle} = Total time for one cycle

DC_{ave} = Proportion of time the system is active
I = Peak or nominal current drawn while active
I_{ave} = Average current over full cycle
P = Estimated power consumption in Watts

Charging and draining tests were conducted on the selected power supply components. Overall, results indicated that the selected components would be able to power the system for the duration that it needed to be powered, regardless of the weather conditions.

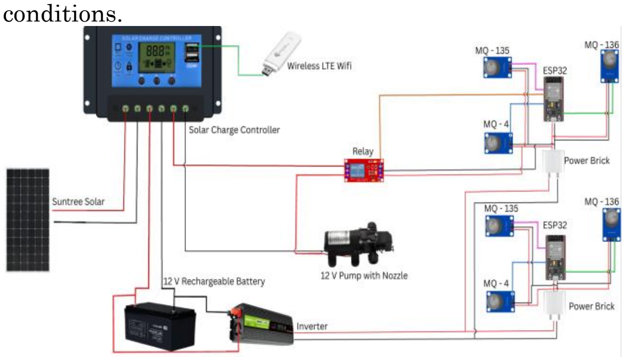


Fig. 4. System Architecture

Figure 4 illustrates the system's circuit connections. The sensors, microcontroller, and relay will be housed in a commercial junction box, while other components' placement depends on the installation site layout. The USB Wi-Fi modem (optional) would only be necessary for farms lacking existing Wi-Fi connectivity.

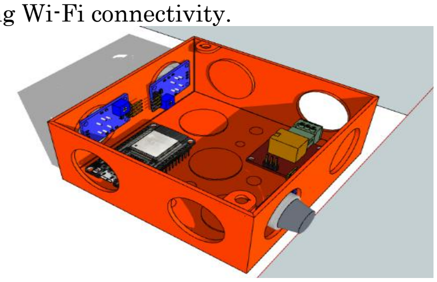


Fig. 5. Prototype Design

Figure 5 shows the design of the prototype, with all the components placed within the junction box, which serves as the housing for the components. Three holes within the junction box were purposefully kept open as these would be where the connections to the misting system and power source were made, as represented by Figure 4.

2.3 System Development Phase

The development phase of the air quality monitoring system included the integration of hardware and software innovations. The developmental phase, which follows the prototype process indicated in the research design, guarantees that the system is functional, reliable, and user-friendly.

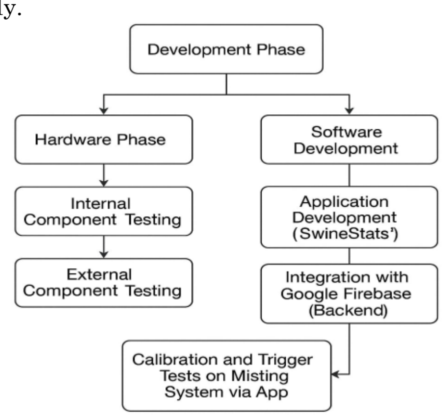


Fig. 6. System Development Phase Breakdown

The development phase is broken down into the hardware phase as shown above, which consists of testing the internal and external components, and the software development phase, which consists of the development of the application, which was named "SwineStats," and its integration into Google Firebase, which served as the backend. Trigger tests were also conducted on the misting system using the application prior to implementation, and calibration, which was done after a two-day preheating period, confirmed an 8.25 – 8.63% deviation in the misting system's calibration against commercial gas sensors.

Fig. 7. Application login page

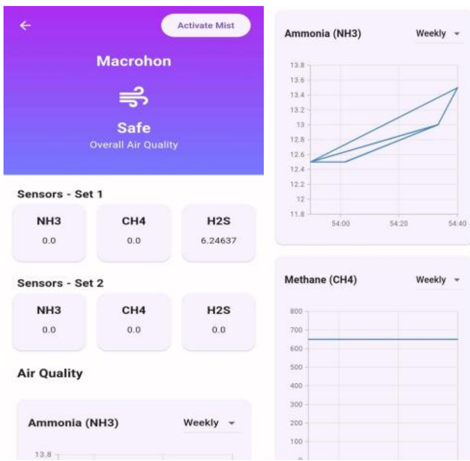


Fig. 8. Application interface, consisting of the real-time readings (left) and the graphs (right)

2.4 Statistical Treatment

The following statistical tools and methods were used in this study to ensure that the data obtained during the date gathering phase was depicted most accurately.

Descriptive Statistical Analysis. Before advanced analysis, the dataset was simplified using descriptive statistics—focusing on mean (central tendency) and variance (variability). The mean clarified the data's characteristics, while the variance assessed reliability. These methods provided quick, interpretable insights to support further analysis.

Cronbach's alpha. Cronbach's alpha was computed for the two surveys conducted to assess whether the results of the surveys were reliable enough to be deemed significant using the items' variance and covariance.

Wilcoxon Signed Rank Test. A repeated measures test was used to assess the efficacy of the misting system. Being the non-parametric counterpart of the paired t-test, it determines whether there is a significant difference in the gas readings before and after misting.

$$W = \sum_{i=1}^{N_r} [sgn(x_{2i} - X_{1i}) * R_i] \quad \text{(Eq. 4)}$$

where:

W = Test statistic

N_r = Sample size

$x_{2i};x_{1i}$ = Corresponding ranked pairs

sgn = Sign function

R_i = Rank i

3. RESULTS AND DISCUSSION

3.1 Needs Assessment Survey Results

The needs assessment surveyed 30 respondents, comprising 29 personnel from two farms and 1 expert from the city veterinarian's office. Most participants were male with low-to-middle income backgrounds. Conducted during the planning phase, the survey focused on improving pig health and biosecurity through monitoring environmental factors like gas levels. It also gauged respondents' willingness to adopt a remote monitoring system for these purposes.

Table 1. Needs Assessment

Question	Scale					Mean	Cronbach's Alpha
	SA (5)	A (4)	N (3)	D (2)	SD (1)		
No. 1	16	10	4	0	0	4.40	0.728 - Acceptable
No. 2	11	16	3	0	0	4.27	
No. 3	10	15	5	0	0	4.17	
No. 4	10	17	3	0	0	4.23	
No. 5	12	17	1	0	0	4.37	

Table 1 above shows the responses to each question of the needs assessment survey, as well as the mean and Cronbach's alpha. Overall, survey results indicate no negative feedback and acceptable reliability.

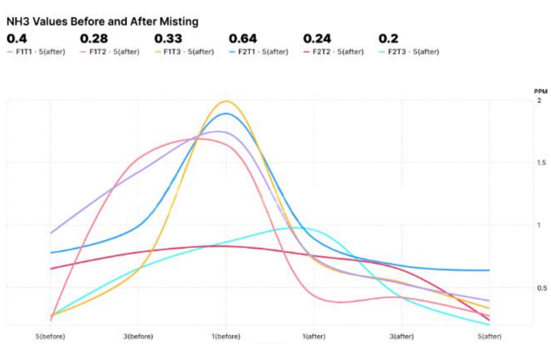
3.2 Effect of Misting System on Gas Concentrations

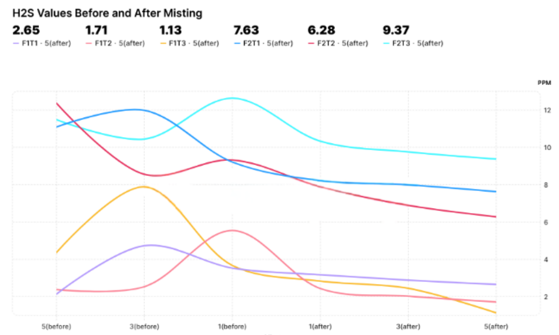
This analysis investigates the effect of spraying the misting solution, which is composed of Virkon S (potassium peroxymonosulfate and sodium chloride) and water, on the gas concentrations in Macrohon Integrated Farm (F1) and Mike's Farm (F2) and was conducted using the manual trigger system. The data was recorded at different points in time throughout the implementation of the study, and three trials (T1, T2, and T3) were conducted, with measurements recorded 5 minutes before and after misting.

Table 2. Gas Values Before and After Misting

Trial	NH_3		CH_4		H_2S	
	Before	After	Before	After	Before	After
F1T1	.933	.395	.764	.245	2.133	2.654
F1T2	.232	.275	.468	.592	2.383	1.709
F1T3	.275	.333	.638	.558	4.359	1.130
F2T1	.778	.638	.689	.625	11.09	7.265
F2T2	.650	.238	.962	.550	12.365	6.275
F2T3	.272	.203	.332	.585	11.482	9.373

Table 2 shows the raw data of the farms before and after misting, showing a decrease in ammonia (NH_3), methane (CH_4), and hydrogen sulfide (H_2S) concentrations following the application of Virkon S. Potassium peroxymonosulfate, a strong oxidizing agent present in Virkon S, is known to oxidize a wide range of compounds (Congzheng Li, 2025). The reduction in NH_3 concentration may be attributed to nitrogen loss through oxidation to nitrogen gas or nitrate compounds, as per observation (Juan Mei, 2022). While the interaction between potassium peroxymonosulfate and CH_4 is generally limited under ambient conditions, some studies suggest partial oxidation pathways may occur under specific circumstances which convert CH_4 to CO_2 (Xinping Li, 2023). H_2S, on the other hand, is readily oxidized to elemental sulfur, sulfite, or sulfate by potassium peroxymonosulfate (Betterton, 1990).





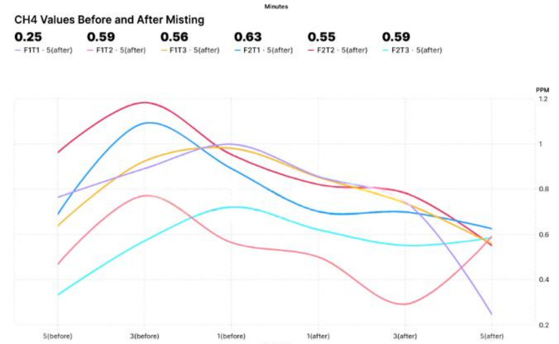
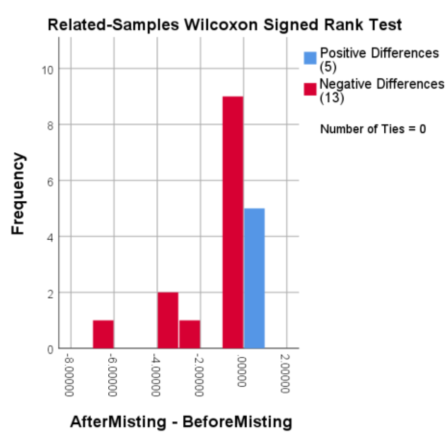


Fig. 9. Graphical representation before and after misting of (a) NH_3, (b) H_2S, and (c) CH_4

Figure 9 illustrates the average gas readings over time, as recorded by the system at two-minute intervals. The first and last values were labeled in Table 2, whereas the system recorded the gaps in between as shown by. The data shows slight changes on both sides, but it is not a good indicator by itself without ample statistical treatment. The bold numbers at the top of the graph represent the final values of each individual trial rounded to the nearest hundredth, which was taken 5 minutes after misting for each test.



Related-Samples Wilcoxon Signed Rank Test Summary

Total N	18
Test Statistic	29.000
Standard Error	22.962
Standardized Test Statistic	-2.461
Asymptotic Sig.(2-sided test)	.014

Fig. 10. Wilcoxon Signed Rank Test Results, including the frequency table (above) the summary of the test (below)

The figure above shows the results of the Wilcoxon signed-rank test. Figure 10 shows the frequency distribution of the results of subtracting the values of each gas reading before misting from the values after misting. Results indicate a decrease in gas concentrations as shown by the graph, and are statistically relevant as per the p-value of .014.

3.3 End Users Feedback Survey Results

The end users feedback survey used the same respondents as the needs assessment survey, only this time the survey was conducted after the implementation phase. It focused on the experience of the users with the device and application, and whether it helped with monitoring gas levels.

Table 3. End Users Feedback Assessment

Question	Scale					Mean	Cronbach's Alpha
	SA (5)	A (4)	N (3)	D (2)	SD (1)		
No. 1	7	16	7	0	0	4.00	0.734 - Acceptable
No. 2	12	14	4	0	0	4.27	
No. 3	4	16	10	0	0	3.80	
No. 4	6	19	5	0	0	4.03	
No. 5	10	17	3	0	0	4.23	

Table 3 shows overall positive feedback for both the system and app, with acceptable reliability and no negative responses. Specifically, 5 out of 6 users found the app easy to use, 9 out of 10 respondents reported the device requires minimal maintenance, and 2 out of 3 users agreed it helps address farm odor issues.

4. CONCLUSIONS

The results of the study highlight the need for an air quality monitoring system in pig farms in the Philippines, and surveys conducted on two farms in Zamboanga City show support for this. System implementation showed significant correlations between several variables, and there was a significant difference in gas readings before and after misting. Overall, the successful one-month implementation of the SwineStats air quality monitoring and control system marks a significant step in integrating IoT into Zamboanga City's agricultural sector. However, various improvements can be made to improve the implementation of the system, primarily through using PM-type sensors instead of MQ-type sensors for better sensor accuracy, downsizing the power supply for a more compact build, and integrating humidity sensors and AI for additional functionality.

5. ACKNOWLEDGMENTS

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