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Effects of Vibration Sensor on Mitigation Risk of Halal Chicken Slaughtering System

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ABSTRACT

Ensuring compliance with halal standards in poultry slaughtering involves both following religious principles and implementing strict scientific and technological measures. Integrating Internet of Things (IoT) technology provides opportunities to enhance the reliability and objectivity of halal verification processes, particularly in identifying critical control points, such as animal death, specifically the death of chickens during the slaughter process, before entering the scalding stage. The present study aimed to design a halal risk mitigation system based on IoT, focusing on the critical point of complete chicken death, defined as the total absence of movement in the chicken after slaughter, through critical analysis. It is known that the stage between post-slaughter and pre-burning is the most crucial phase, where the highest risk is that the chicken has not entirely died due to ineffective slaughter. This system was developed using a NodeMCU ESP8266 microcontroller connected to a vibration sensor or passive infrared sensor and was equipped with real-time notifications via the Thingspeak cloud dashboard, indicating the waiting time for complete death and the number of vibrations. Testing on 30 chickens demonstrated a detection accuracy of 92.5% compared to manual observations by halal auditors, with consistent performance across different environmental conditions. This system can detect the movement of chicken remains after slaughter in an average of 15 to 20 seconds, providing an early warning of potential halal violations rules. The current results demonstrated that the vibration sensor effectively facilitated the execution of halal slaughtering principles through an early-warning mechanism designed to prevent chickens from entering the scalding phase while still alive. This ensures the humane death of chickens and the regulation of halal critical control points in line with the Indonesian national standard for halal poultry slaughter.

Keywords: Criticality analysis, Halal slaughter, Risk management, Poultry industry, Vibration sensor

INTRODUCTION

The global demand for halal products continues to grow significantly worldwide. This increase is driven not only by the growing Muslim population but also by consumers from different backgrounds who are increasingly valuing food integrity, safety, and quality (Herdiana et al., 2024). In Indonesia, which has the largest Muslim population, halal certification for animal food products goes beyond a religious obligation; it has also become an ethical and regulatory standard within the national food system (Pradana et al., 2024). As a result, the halal aspect has become a primary focus in supervising and managing the food supply chain, particularly in processes directly related to sharia requirements, such as slaughtering in slaughterhouses.

One of the most crucial issues in the halal poultry slaughter process is to ensure that each chicken experiences complete death as a direct result of slaughter, defined as the complete absence of movement in the chicken after slaughter (Nielsen et al., 2019). This complete death is one of the main requirements for the validity of slaughter according to Islamic law (Jelan et al., 2024). According to the Indonesian National Standard (SNI) 99002:2016 on halal slaughter of poultry (BSN, 2016), the chickens should be entirely dead due to the neck incision before entering the scalding stage (Asih and Sopha, 2024), the animal must be fully deceased after the three main tubes, throat, respiratory tract, and major blood

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vessels are cut, prior to entering the scalding stage (Guinebretière et al., 2024). The SNI, developed by the National Standardization Agency of Indonesia (BSN), acts as a national benchmark to ensure product quality, safety, and compliance with regulations (Rosiawan et al., 2018). However, field practice indicated that many chickens are not completely dead from slaughter and instead die from the soaking process, which then became a critical point in the halal assurance system.

In the context of halal chicken slaughter, it is essential to distinguish between complete death and brain stem death (Shahdan et al., 2017). Complete death refers to the total halt of all biological functions, including reflexes and voluntary movements, after slaughter, indicating that the animal has died solely as a result of the cut (Espinosa, 2024). In contrast, brain stem death is a more complex condition characterized by the irreversible loss of brain stem function, which may still permit residual reflexes or spasmodic movements even if consciousness is lost (Fuseini, 2019; Friedman et al., 2021). Determining brain stem death through histopathological examination is the gold standard; however, in practical slaughterhouse settings, such examination is not feasible. Instead, observable behavioral indicators such as persistent residual motion, muscle spasms, or reflexive leg movements are widely used as non-invasive indicators of incomplete brain stem shutdown (Sazili et al., 2023; Ibrahim et al., 2024).

Incomplete death in poultry during slaughter is especially problematic because, under Islamic law, the chickens are required to die directly after slaughter (Samoylov et al., 2023). If the chicken dies due to other conditions, such as hot water during the scalding process, the meat is assumed not halal (Thaha et al., 2023). In modern industry, detection of complete death is often only done visually by operators, which is prone to human error, especially in large-scale and process-intensive production (Vieira et al., 2024). These findings highlighted a critical need for a real-time and objective monitoring system to verify complete death before the scalding stage.

To ensure a complete death according to the sharia, the monitoring system must detect not only the absence of spasmodic movements, but also ensure that all physiological functions have stopped, including both reflex responses and heartbeats. This will reduce the risk of the chicken dying from scalding instead of slaughter and maintain the halal status of the products.

Conventional chicken slaughtering systems in many slaughterhouses, especially on an industrial scale, still rely on manual supervision and visual sampling (Agrawal et al., 2025). In this model, staff observe whether the chicken has stopped moving and then allow the chicken to enter the hot water immersion tank (Astruc and Terlouw, 2023). However, not all movements (or lack thereof) are valid indicators of complete death. Spasmodic or convulsive movements may occur as a result of nervous or muscular system activity that has not entirely shut down, even though the chicken appears unconscious.

This weakness is worsened by production pressures in modern industrial systems, which prioritize speed and efficiency over accuracy regarding halal standards. In systems operating at an automated conveyor pace, every second matters, and a thorough examination of the chicken's health after slaughter is often neglected (Voogt et al., 2023). As a result, many chickens still have brain stem activity during the scalding stage and die from heat, which automatically invalidates the halal status of the product.

In response to these challenges, Internet of Things (IoT)-based approaches offer great potential in halal control systems (Alkahtani et al., 2024). One solution being developed was the use of vibration sensors or passive infrared motion sensors (PIR sensors) to detect residual motion post-slaughter (Verma et al., 2021). These sensors can be installed on conveyor lines or inspection stations before the chickens enter the scalding tank. When movement or convulsions are detected, indicating that the chicken is not fully dead, the system will give an alarm or stop the conveyor automatically.

To identify the most critical failure points in this process, the failure mode, effect, and criticality analysis method was used (Chennoufi and Chakhrit, 2024). This method maps all stages of the slaughter process and detects potential failures such as incomplete slaughter, delayed slaughter, or operator error (La Fata et al., 2022). These evaluations inform the development of an IoT-enabled automated control system designed to perform preventive, corrective, and predictive functions.

The IoT-based complete death detection system addresses technical challenges in chicken slaughtering and ensures adherence to national halal standards. By automating the documentation of slaughter compliance, the system enhances operational transparency and supports integration into wider halal certification frameworks (Maryuliano and Andarwulan, 2024). The system, integrated with a real-time dashboard and cloud storage, allows for transparent monitoring and enhances public trust in the halal industry.

It has been stated in several studies conducted by Islam et al. (2023), Ibrahim et al. (2024), and Suliman et al. (2024) that there is still a significant gap in integrating technological systems that address the core of the halal issue, namely, deaths due to slaughter. Many studies have focused on post-harvest traceability, the use of blockchain in the supply chain, or managerial approaches to halal risk (Rahim et al., 2020). As demonstrated in a study of Sari et al. (2024), sustainable strategic planning and management driven by green management, digital transformation, and halal business management significantly enhances the ecological (Ahmad et al., 2024), social, and economic performance of halal-oriented micro, small, and medium enterprises (MSMEs; Fischer and Nisa, 2025). However, no approach automatically detects the life-and-death status of chickens immediately after slaughter.

By integrating the failure mode, effects, and criticality analysis (FMECA) method for risk identification and IoT technology for residual motion detection, the proposed system specifically addresses the most critical issue in the slaughter process (Ghiaci and Ghoushchi, 2023). This goes beyond production efficiency; it is about preserving the integrity of Shariah, a non-negotiable value in the halal food system (Amijaya et al., 2024). Integrating technology into the halal assurance system should be part of the national strategy to develop a halal industry 4.0 ecosystem, featuring IoT, automation, and digital traceability tools (Ellahi et al., 2025). By utilizing IoT, sensor data, and automatic alarm systems, slaughterhouses can enhance the effectiveness and efficiency of their production processes while fostering stronger relationships with consumers domestically and internationally, ultimately leading to increased market acceptance.

In the context of increasing global competition and rising demands for halal meat, Indonesia has strategic potential to lead in the technological advancement of the halal industry (Sucipto et al., 2020). The present study aimed to develop a halal risk mitigation system utilizing the IoT, supported by FMECA analysis, focusing on the critical aspect of ensuring proper chicken death, which is characterized by the complete lack of movement in the chicken after slaughter, as determined through criticality analysis.

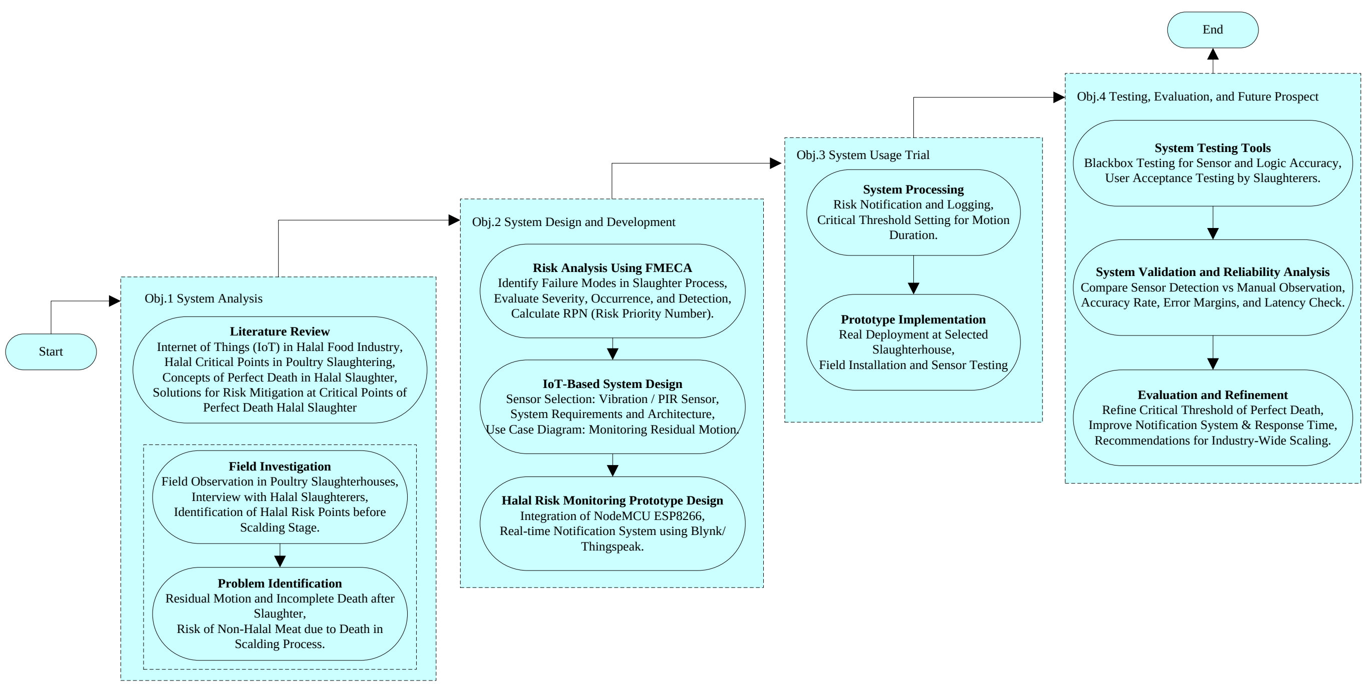

Figure 1. Flowchart of IoT-based halal risk mitigation system design (Designed by authors).

MATERIALS AND METHODS

Ethical approval

The present study received ethical approval from the Ethics Committee of the Halal Product Process Assistance Institution (LP3H) of the Indonesian Islamic Boarding School Association under approval code LP3H.IPI/EA/027/VII/2025.

Materials and tools

The main components of the IoT system included a NodeMCU ESP8266 microcontroller, which served as the main data processing unit and IoT signal transmitter, a vibration sensor module or PIR HC-SR501 to detect residual chicken movement after slaughter, an LED with 520-525 lux as a visual indicator, and a Wi-Fi module to transmit data to an IoT platform-based monitoring server such as Blynk or Thingspeak.

Technology approaches

The present study utilized an applied engineering approach to develop a technology-driven system for halal risk mitigation. The method involves four stages. First, system analysis identified halal risks, especially incomplete death before scalding, through literature review and field observations. Second, system design and development applied FMECA to map critical failure points and developed an IoT-based prototype using vibration/PIR sensors with a NodeMCU ESP8266 microcontroller. Third, a field trial tested the prototype in a slaughterhouse to detect residual motion and assess real-time performance. Finally, the system evaluation validated accuracy against halal auditor observations and examined stability under operational conditions.

System analysis

This stage focused on identifying halal risks in the chicken slaughtering process, particularly the risk of incomplete death before scalding. The analysis identified potential failure modes in the slaughtering process and ranked them using the FMECA framework to find the most important control points that need technological intervention. The criticality value was used as a composite risk indicator, derived from severity, occurrence, and detectability metrics. In the present study, the calculation was based on $\alpha = 0.45$ (Contribution to total failures), $\beta = 0.95$ (Severity in terms of Sharia impact), and $\lambda_p = 0.035$ failures per hour (Occurrence frequency). Higher C values indicated greater potential impact on system integrity and halal compliance. The value of λ_p represented the estimated failure rate, derived from field observations or historical production records.

Table 1. List of materials for the design of an IoT-based halal risk mitigation system

Component name	Specification	Function
ESP8266 microcontroller	NodeMCU ESP8266 (Wi-Fi enabled, GPIO ≥ 6)	Main unit of the data processor and IoT signal sender
Breadboard	Mini breadboard (400/830 dots)	Place for electronic circuit assembly
Jumper Cable	Male-to-Male and Male-to-Female wires	Connecting components on the breadboard
Relay Module	1 Channel 5V Relay Module	Controls output devices such as lights or buzzers
Buzzer (optional)	5V Active Buzzer Module	Alternative sound alarm when the chicken is not completely dead
Wi- Fi/ Communication module (internal)	Embedded in ESP8266	Send data to the dashboard or server
Enclosure/Box	ABS plastic box	Protects the device from dust and moisture
IoT Server/Dashboard	Platforms such as Blynk, Thingspeak, or Firebase	Displays sensor data in residual motion
USB cable	Micro USB to USB-A	Connects ESP8266 to a computer/power source
Android/iOS Smartphone (Optional)	Android 8.0+ / iOS 13+ RAM: ≥2 GB Connection: Wi-Fi Storage: ≥16 GB	Access real-time monitoring dashboard (Blynk/Thingspeak) Receive notifications/alarms if the chicken has not died completely Perform remote control of the system (on/off relay) if the system supports it
Supporting Application (Optional)	Blynk IoT Thingspeak Viewer MQTT Dashboard Firebase App	Display sensor status and data logs Provides manual/emergency control

System design and development

In the system design stage, FMECA was applied to identify critical failure points in the slaughtering process. An IoT-based system utilizing vibration or PIR sensors and NodeMCU ESP8266 has been developed to detect post-slaughter movement and send real-time alerts via platforms such as Blynk or Thingspeak. This enables early warnings and objective halal compliance monitoring, comprising several key components, as detailed in Table 1.

System usage trial

The system was implemented in a real slaughterhouse to assess effectiveness and gather user feedback. The system detected residual movements within a time threshold and alerted operators if chickens were not entirely dead, as demonstrated through trials conducted on 30 chickens. The methodological framework of the present study (Figure 1) comprised four sequential stages: system analysis, design and development, field testing, and evaluation. Figure 2 illustrates the system workflow. The IoT-based vibration sensor system prototype was then tested under actual slaughterhouse conditions to assess its reliability, focusing on sensor performance and real-time data consistency (Figure 3).

Testing and evaluation

System validation involved black-box testing and user acceptance testing to confirm that the system consistently detects residual motion in real operational conditions and complies with halal assessments. Accuracy was assessed by comparing the system output with manual observations, as outlined in the methodological framework (Figure 1) and demonstrated in the system workflow (Figure 2). The comparative results between the sensor readings and manual observations were presented in Figure 3, which was created by the authors using Microsoft Visio and was not adapted from any external source. Improvements were implemented based on the results, focusing on sensor sensitivity and logic refinement.

Table 2. Risk factors associated with halal chicken meat production process based on SNI 99002:2016 in Pasuruan Chicken Slaughter Center, Indonesia (2025)

Process stages	Risk factor	Risk code	Risk priority level	α	β	λ_p (per hour)	t (hour)	C	Recommendation action
Chicken Arrival	Chicken from non-halal certified sources	R1	Acceptable risk	0.30	0.80	0.015	100	0.36	Supplier halal certificate verification and IoT tracking
Chicken Transport	The chicken died during transportation	R2	Acceptable risk	0.25	0.75	0.020	100	0.375	Use ventilation containers and an on/off monitoring system
Ante-mortem Inspection	Sick/unfit chicken not detected	R3	Acceptable risk	0.20	0.85	0.018	100	0.306	Chicken health audit and inspection officer certification
Slaughter	The slaughterer is not halal certified	R5	High-priority risk	0.40	0.90	0.025	100	0.9	Require halal slaughterer certification and periodic sharia audit
Slaughter	Improper cutting point	R7	High-priority risk	0.35	0.85	0.030	100	0.893	Sharia cutting point training and slaughter verification
Slaughter	Chicken is not completely dead	R8	Extreme priority risk	0.45	0.95	0.035	100	1.496	Post-slaughter Vibration Sensor for residual motion detection, and perfect time of death monitoring
Blood Removal	Blood does not come out completely	R9	Acceptable risk	0.25	0.70	0.012	100	0.21	Blood flow monitoring and slaughter SOP training
Hot Water Immersion	Water contaminated with impurities	R10	Acceptable risk	0.20	0.65	0.010	100	0.13	Separate the temperature sensor and water circulation system
Offal Handling	Contact with unclean internal parts	R11	Acceptable risk	0.15	0.60	0.010	100	0.09	Separate offal area and equipment cleanliness audit
Packaging and Storage	No halal label or improper storage temp	R13	Acceptable risk	0.10	0.50	0.008	100	0.04	Digital labeling and automatic temperature monitoring

Note: α is the proportional weight of risk severity to overall process; β is the proportional weight of sharia criticality level; λ_p (per hour) is the estimated failure rate, derived from field observations or historical production records; t (hour) is the exposure time considered in the risk evaluation; and C is criticality index, calculated by combining α, β, λ_p, and t; higher values indicate higher priority for mitigation.

RESULT AND DISCUSSION

Mapping critical points of halal risk in the slaughter process

Based on the data obtained in Table 2, as well as the results of observations and analysis using the FMECA method, this analysis identified the post-slaughter to pre-scalding stages as the most critical halal risk points, accounting for 45% of the overall risk distribution (α = 0.45), with an extreme priority risk category (C = 1.496). This stage was crucial in ensuring that the chicken experiences complete death, which is a necessary condition for slaughter according to Islamic law and in accordance with the SNI 99002: 2016 guideline (Musawa et al., 2024). The SNI 99002:2016 standard specifies the halal slaughtering procedures for poultry in Indonesia, highlighting that the animal should be completely dead after slaughter to be considered halal. One of the most significant risks occurs when the chicken does not die instantly during slaughter but instead dies from hot water scalding, which renders the meat non-halal according to Sharia (Ramli et al., 2024).

Within the FMECA analysis framework, the highest risk was identified in R8 (Chickens did not die completely), which was classified as an extreme priority risk category. This risk indicated that the failure has a direct and profound impact on the halal status of the products. The analysis indicated that the C value reached 1.496, the highest among all identified risks (Table 2). This finding highlighted that failure in R8 (chickens did not die completely) had the most significant impact on halal compliance and overall system integrity, which indicated that incomplete chicken mortality is a significant and critical issue that needs technological solutions.

As illustrated in Table 2, the values of α and β were assigned according to each risk factor's proportional impact and the level of Sharia criticality within the overall process, with assumed values derived from the literature. The highest C index was recorded at R8 (Chickens were not completely dead, C = 1.496), indicating the most critical risk and the highest priority for mitigation with an IoT-based death detection system.

The present study demonstrated that the IoT-based vibration sensor system successfully detected residual movements in slaughtered chickens with an accuracy of 92.5% compared to halal auditor observations. These findings indicated that the system could objectively monitor incomplete death within 15-20 seconds post-slaughter, thereby reducing the risk of chickens entering the scalding tank while still alive. Similar to the present study, Neil et al. (2024) reported that spasms and reflexes are reliable indicators of incomplete death, as historically confirmed through manual observation. In contrast, the IoT-based system provided automated and real-time detection, overcoming the subjectivity of human judgment. Furthermore, while Ismail and Huda (2024) highlighted the urgent need for innovation in post-slaughter monitoring, the present results provided empirical evidence that such an innovation was technically feasible and effective under real slaughterhouse conditions.

The use of this innovative vibration sensor technology aligns with the findings of Hidayati et al. (2024), who emphasize that certified slaughtering practices and technological interventions are crucial for ensuring halal compliance, particularly in industrial settings prone to inconsistencies. To address related risks, the present study applied an IoT-based real-time monitoring system using vibration or PIR sensors to detect post-slaughter movement. The system alerted when signs of life lasted more than 3 minutes, in line with manual slaughter standards that require complete blood loss. Additionally, it featured visual alarms and digital audits to support halal verification.

Figure 2 illustrates the workflow of an IoT-based halal risk mitigation system designed to detect the perfect death of chickens after slaughter, addressing critical risks identified through FMECA analysis, particularly the failure of chickens to die from the slaughter cut, which may result in death during the hot water scalding process and thus invalidate the halal status of the meat. The system begins with activating a power supply to the ESP8266 microcontroller, which was connected to a vibration or PIR sensor that detected post-slaughter residual motion. When movement was detected, the ESP8266 processed the signal and activated a relay module to trigger a visual indicator such as an LED light, serving as a warning to operators. In parallel, the data is transmitted via Wi-Fi to a cloud-based dashboard for real-time monitoring and digital traceability. The system also included a maintenance feature that enabled users to monitor operational indicators and perform recalibration as needed to ensure ongoing accuracy and compliance with halal standards.

The system included cloud dashboard integration (Thingspeak or Blynk), enabling remote monitoring, live data visualization, and event history recording, essential for traceability and auditability as mandated by SNI 99002:2016. The integration of these features supported data-driven halal assurance by reducing reliance on manual inspection. According to Fuseini et al. (2021), visual inspection alone cannot guarantee the complete loss of brainstem function, making objective sensor-based detection essential for ensuring slaughter compliance. Additionally, Nusran et al. (2023) highlighted the potential of IoT to enhance transparency and automation in halal verification, aligning with trends in industrial digitalization. The wiring schematic indicated that the system's architecture facilitated parallel computing, enabling the simultaneous monitoring of multiple components of chickens. With adjustable sensitivity settings and routine maintenance, the system demonstrated excellent adaptability to diverse operational conditions. This compact design enhanced halal control points, facilitated digital transformation, and signified a strategic innovation for developing a modern, dependable, and technologically advanced halal framework industry.

Table 3. Residual motion detection test results, including vibration sensor versus manual observation for detecting complete death in halal chicken slaughter

Chicken number	Vibration sensor detection (residual motion duration)	Sensor status	Halal auditor's visual observation	Auditor's status
1	45 seconds	Perfectly Dead	No Motion	Perfectly Dead
2	2 min 20 sec	Not Dead	Slight Spasms	Not Dead
3	1 min 10 sec	Perfectly Dead	No Motion	Perfectly Dead
4	3 min 30 sec	Not Dead	Neck Movement Detected	Not Dead
5	55 seconds	Perfectly Dead	No Motion	Perfectly Dead
6	4 min 05 sec	Not Dead	Leg Vibration Detected	Not Dead
7	1 min 50 sec	Perfectly Dead	No Motion	Perfectly Dead
8	3 min 10 sec	Not Dead	Minor Movements Observed	Not Dead
9	50 seconds	Perfectly Dead	No Motion	Perfectly Dead
10	2 min 40 sec	Not Dead	Delayed Minor Spasms	Not Dead
11	58 seconds	Perfectly Dead	No Motion	Perfectly Dead
12	3 min 15 sec	Not Dead	Neck Spasms	Not Dead
13	1 min 05 sec	Perfectly Dead	No Motion	Perfectly Dead
14	2 min 55 sec	Not Dead	Neck Twitches	Not Dead
15	46 seconds	Perfectly Dead	No Motion	Perfectly Dead
16	3 min 45 sec	Not Dead	Leg Movement Detected	Not Dead
17	49 seconds	Perfectly Dead	No Motion	Perfectly Dead
18	2 min 10 sec	Not Dead	Slight Reflexes	Not Dead
19	1 min 30 sec	Perfectly Dead	No Motion	Perfectly Dead
20	3 min 05 sec	Not Dead	Subtle Movements	Not Dead
21	47 seconds	Perfectly Dead	No Motion	Perfectly Dead
22	2 min 35 sec	Not Dead	Weak Spasms	Not Dead
23	55 seconds	Perfectly Dead	No Motion	Perfectly Dead
24	3 min 20 sec	Not Dead	Limb Reflexes	Not Dead
25	52 seconds	Perfectly Dead	No Motion	Perfectly Dead
26	4 min 00 sec	Not Dead	Persistent Movement	Not Dead
27	59 seconds	Perfectly Dead	No Motion	Perfectly Dead
28	2 min 25 sec	Not Dead	Reflex Detected	Not Dead
29	1 min 15 sec	Perfectly Dead	No Motion	Perfectly Dead
30	3 min 50 sec	Not Dead	Leg Twitching	Not Dead

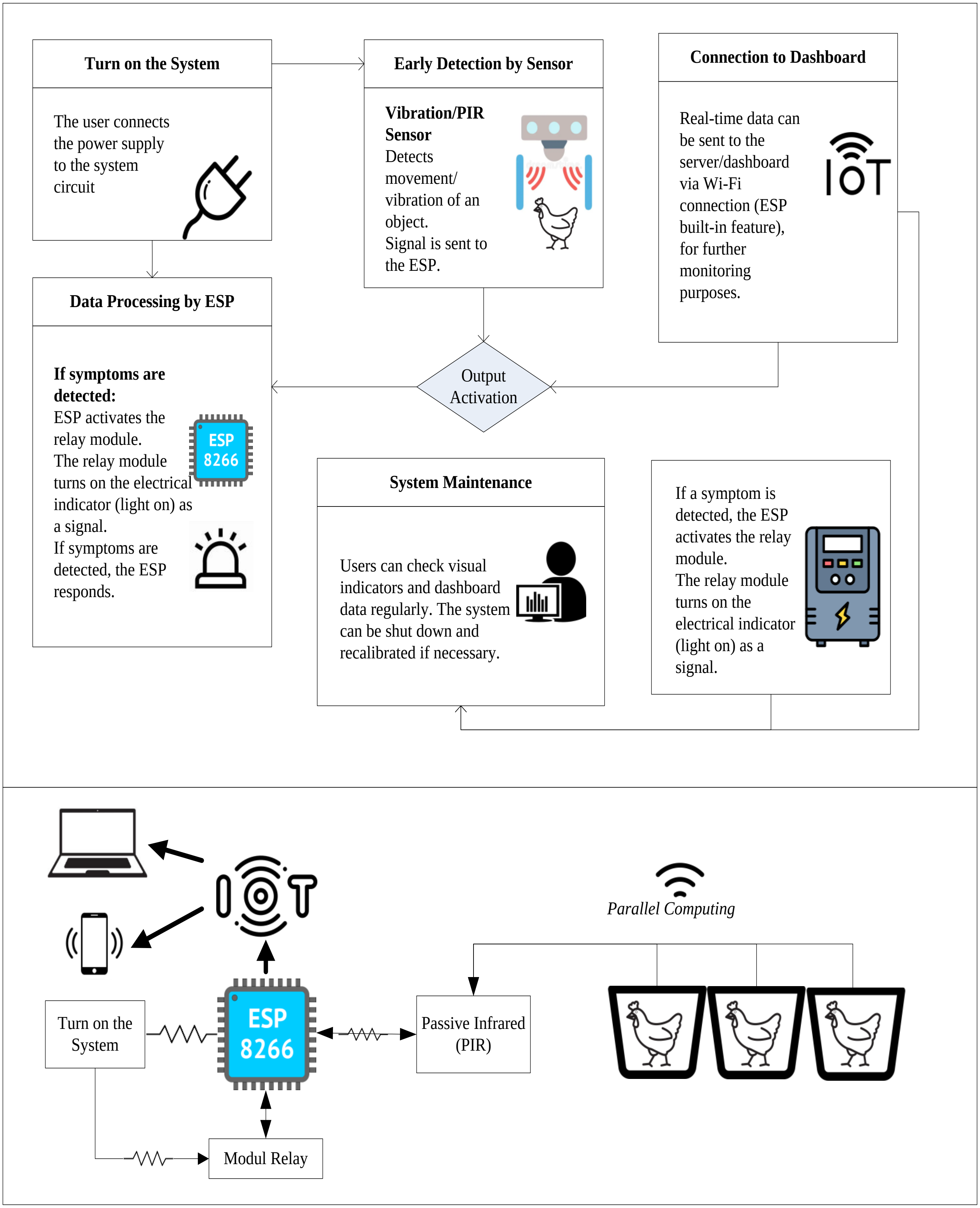

Figure 2. IoT-based system workflow for detecting complete death in halal chicken slaughter (Designed by authors).

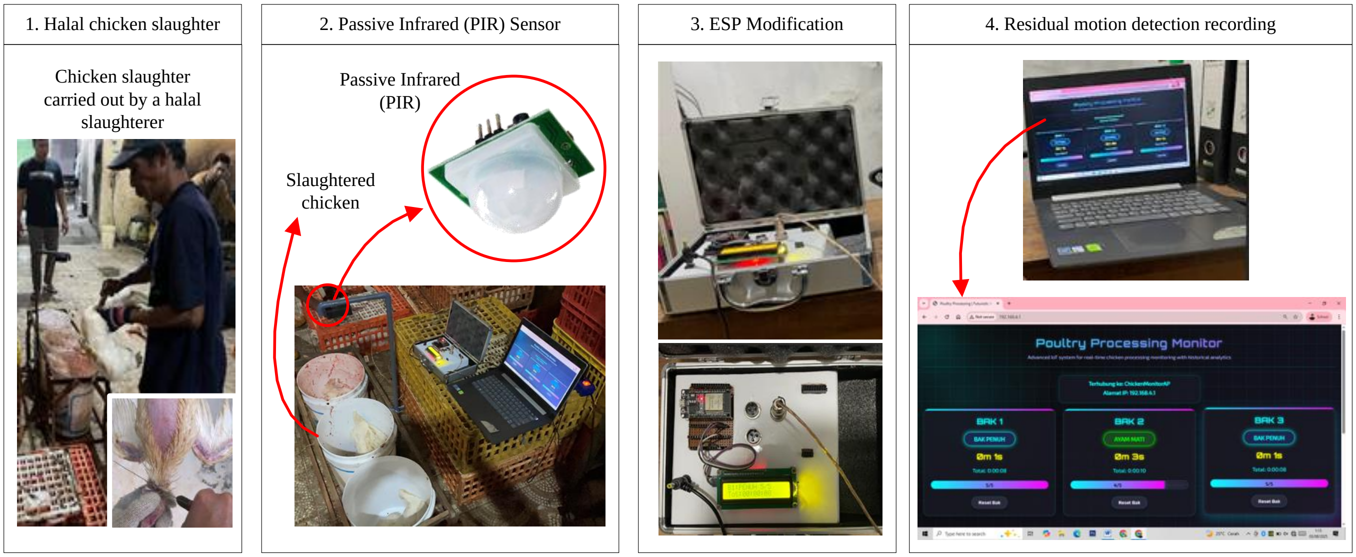

Figure 3. Residual motion detector trial after halal chicken slaughter in Pasuruan Chicken Slaughter Center, Indonesia

System usage trial

The prototype of the IoT-based halal risk mitigation system was tested on 30 chickens at a slaughterhouse to evaluate its accuracy and reliability in real operational settings. The system, equipped with an ESP8266 microcontroller and vibration sensor, successfully detected residual post-slaughter movements within 0 to 5 minutes, achieving 92.5% accuracy compared to manual halal auditor assessments. In six cases, the system provided early warnings, which were later verified as accurate through manual confirmation observation. The system detected movement within 15-20 seconds of activation, demonstrating real-time responsiveness, which is essential for high-speed slaughter processes. It accurately identified subtle indicators such as muscle spasms, establishing itself as a dependable early warning instrument for potential halal violations.

Apart from accuracy and sensitivity, the system demonstrated stable performance under different lighting and temperature conditions (22 to 30°C) during brief trials conducted in a commercial poultry slaughterhouse in Pasuruan, Indonesia. Although the test consistently yielded reliable results without requiring recalibration, it was conducted at only one location and within a limited scope timeframe. These findings supported the feasibility of integrating the system into industrial slaughter lines as a decision-support tool for verifying complete chicken death. The system plays a vital role in enhancing halal assurance by providing rapid response, environmental resilience, and high-precision technology.

Figure 3 shows the system usage trial of the IoT-based residual motion detector after halal chicken slaughter. The process started with halal slaughtering performed by a certified slaughterer, followed by the use of a PIR sensor to detect residual motion in the slaughtered chickens. The ESP8266 microcontroller was then customized and connected to the sensor to collect signals and trigger the relay module. Finally, the remaining motion data were recorded and displayed on a digital dashboard for monitoring and traceability. Table 3 presents the results of this system trial, comparing sensor detection with manual observations by halal auditors to evaluate accuracy.

Testing and prospects

The present study introduced a vibration sensor-based system designed to detect residual motion in chickens after slaughter, in accordance with Islamic law and SNI 99002:2016. Residual movements such as spasms or reflexes indicate incomplete physiological death.

The present study utilized manual observation by certified halal auditors as the reference standard for validating the sensor system. However, considering the potential for human error, the sensor-based system provided a more objective and consistent way to detect residual motion, especially in high-volume operational settings. The average detection time for non-compliant deaths was three minutes and three seconds, matching critical thresholds. In real-time, automated alerts improve decision-making and prevent non-halal processing, making it a valuable tool for strengthening halal assurance in poultry slaughterhouses.

The current findings are in line with the study of Tang et al. (2024), which confirmed that sensor-based monitoring can enhance halal compliance by decreasing reliance on human intervention and improving traceability aspects. Fletcher et al. (2025) stated that post-slaughter residue movement can cause ambiguity in determining death status, so an objective and data-driven approach is needed. Additionally, Ibrahim et al. (2024) demonstrated that the integration of IoT technology into halal critical control points improves monitoring transparency and minimizes the risk of non-compliance, particularly in high-throughput slaughtering facilities. Similarly, Alkahtani et al. (2024) reported that the use of automated sensor systems in smart slaughterhouses significantly enhances the consistency of compliance detection and enables remote auditing within digital halal certification frameworks. These findings highlight the importance of the proposed system for large-scale field trials and real-time integration with cloud-based halal assurance platforms.

CONCLUSION

The present study demonstrated that the IoT-based vibration sensor system successfully detected incomplete death in chickens after slaughter with an accuracy of 92.5% compared to halal auditor observations. These crucial findings indicated that IoT technology had strong potential to strengthen objective and real-time monitoring of halal compliance during the critical post-slaughter to pre-scalding stage. For further studies, it is suggested to evaluate the long-term reliability and stability of the IoT-based vibration sensor system in different slaughterhouse environments, analyze its economic feasibility and scalability for large-scale poultry industries, and investigate integration with blockchain or AI-driven platforms to improve traceability, certification integrity, and consumer trust in halal assurance systems.

DECLARATIONS

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Authors' contributions

Khafizh Rosyidi conducted the research, collected and analyzed the data, and drafted the manuscript. Imam Santoso, Yusuf Wibisono, and Sucipto Sucipto reviewed and edited the manuscript. All authors have read and approved the final edition of the manuscript.

Conflict of interest

The authors declare that there is no conflict of interest related to this study.

Ethical considerations

All authors confirmed that ethical issues such as plagiarism, publication consent, misconduct, data fabrication or falsification, duplicate submission, and redundancy have been thoroughly checked and found to be compliant.

Availability of data and materials

All data generated during the present study are included in this article. Additional information is available from the authors upon reasonable request.

Competing interests

The authors declared no conflict of interest in this article.

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