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IMPROVEMENT ON THE DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AUTOMATIC DEFEATHERING MACHINE

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Abstract
The increasing demand for hygienically processed poultry meat, coupled with the inefficiencies of manual defeathering methods in developing regions, has necessitated the development of automated solutions that integrate thermal control, mechanical plucking, and safety mechanisms. This study presents the design, implementation, and performance evaluation of an improved automatic poultry defeathering machine tailored for small- and medium-scale poultry processors. The system integrates a thermostatically controlled scalding unit, a motor-driven plucking chamber, and a microcontroller-based control system to automate the entire defeathering process with minimal human intervention. Fabricated from mild steel and stainless-steel components for structural integrity and hygiene compliance, the machine employs food-grade rubber plucking fingers and is equipped with safety features such as a float switch and emergency shutoff controls. Performance testing was conducted using freshly slaughtered broiler chickens with an average live weight of 1.5-2.2 kg. The machine achieved a defeathering efficiency of 93.2%, a throughput rate of 85 birds/hour, and a specific energy consumption of 0.19 kWh per bird. The system maintained a consistent scalding temperature with a deviation margin of ±2°C, while ensuring minimal carcass damage. Results show strong agreement with similar automated systems in existing literature, highlighting improvements in precision, repeatability, and operator safety. The integration of thermal and mechanical subsystems with digital automation provides a reliable and scalable solution for improving poultry processing standards in resource-limited environments.

Keywords: Automatic defeathering machine, Poultry processing technology, performance evaluation, Feather removal efficiency

1. Introduction

The poultry industry plays a pivotal role in global agriculture, serving as a major contributor to food security, employment generation, and economic growth, particularly in developing nations. In Nigeria, poultry production has transitioned from a backyard activity into a commercial enterprise due to increasing urbanization, income growth, and changing dietary habits that favor lean animal proteins such as poultry meat [1], [2]. As the demand for poultry products rises, so too does the need to improve the efficiency, hygiene, and scalability of post-slaughter processing systems.

Among the key stages in poultry processing, defeathering the removal of feathers following slaughter remains one of the most labor-intensive and hazardous tasks. In many small- and medium-scale processing centers across Nigeria and Sub-Saharan Africa, defeathering is often performed manually, requiring operators to immerse carcasses in scalding water and subsequently pluck feathers by hand. This exposes workers to thermal injuries, fatigue, and potential ergonomic stress, while also reducing the consistency and quality of the final product [3], [4]. Moreover, manual methods increase the risk of microbial contamination due to excessive human contact and inadequate sanitation measures [5].

Efforts to mechanize defeathering have led to the development of various automatic and semi-automatic machines. While these innovations have reduced labor input, many suffer from design flaws such as inadequate synchronization between scalding and plucking operations, suboptimal temperature control, and limited adaptability to local environmental and economic conditions [6]-[8]. Most notably, prior designs rarely

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incorporate automation and safety interlocks, leading to inefficiencies, higher operating costs, and increased likelihood of carcass damage due to irregular scalding temperatures or poor mechanical handling [9].

The application of mechatronic systems and embedded control technologies presents a compelling solution to these limitations. By integrating sensors, microcontrollers, and intelligent actuators, modern poultry processing systems can be designed to operate with minimal human intervention, enhanced precision, and greater reliability. Microcontroller platforms such as the Arduino-based ATmega328 enable real-time monitoring of scalding temperature, control of timing sequences, and coordination of motor operations, thereby improving throughput and ensuring consistent processing conditions [10], [11]. In addition, temperature sensors like the DS18B20 can provide precise thermal feedback to regulate scalding chambers, improving the loosening of feather follicles and reducing the risk of skin damage [12].

This study presents the design, fabrication, and performance evaluation of an improved automatic poultry defeathering machine tailored to the operational constraints of small and medium-scale poultry processors. The machine integrates a closed-loop temperature-controlled scalding system, a mechanically driven defeathering chamber, and a programmable logic unit to manage operations in sequence. The system architecture emphasizes safety, reliability, and energy efficiency, with features such as automatic shutoff, minimal human contact, and use of locally available materials for cost reduction and ease of maintenance.

Unlike earlier efforts that primarily emphasized mechanical robustness, this research adopts a holistic approach by integrating ergonomics, hygiene, automation, and real-time control into the design. The machine aims to increase processing speed, reduce physical risk to operators, and enhance the quality and safety of poultry meat products. By combining local fabrication techniques with global best practices in system control and food processing, this work contributes meaningfully to the advancement of agro-industrial technologies suited for low-resource settings [13], [14].

2. Literature Review

The global rise in poultry consumption has intensified the need for efficient and hygienic processing systems, particularly in developing countries where demand often outpaces infrastructural modernization. As Ghosh et al. observed, the shift in dietary preferences toward poultry meat has pressured traditional processing methods to evolve, especially in regions experiencing rapid urbanization and income growth [2]. While manual defeathering remains prevalent in many localities, its limitations such as low throughput, inconsistent quality, labor intensiveness, and high contamination risk underscore the urgency for mechanized solutions [3], [4].

Early attempts to mechanize defeathering often emphasized simplicity and cost-effectiveness. Adesanya and Olukunle [4] developed a manually driven feather plucking machine from local materials that operated at 300 rpm and achieved 95% efficiency. Although their design was practical and accessible, its lack of automation limited precision and operator safety. Similarly, Awotunde et al. [6] presented a vertical drum-style defeathering machine, achieving 82% efficiency through mechanical rotation but without any temperature control. These designs, while contextually relevant, highlighted the need for integrated thermal and automation systems to enhance consistency.

Temperature regulation emerged as a critical determinant in several studies. Omidiji et al. [9] demonstrated that maintaining scalding temperatures between 60°C and 90°C significantly affected feather detachment and skin quality. Langkabel reinforced this finding by linking thermal accuracy to microbial control, advocating for more precise and feedback-regulated scalding systems [13]. Elmagd et al. [1] found that scalding and defeathering collectively consumed over 60% of processing energy in slaughterhouses, suggesting that optimizing thermal control would improve both efficiency and sustainability. These insights have informed the direction of modern designs integrating real-time thermal feedback.

Progressively, researchers began incorporating performance optimization techniques. Fadeyibi et al. [12], through empirical analysis, established that a pluck size of 12–14 mm and a clearance of 22-38 mm in a circular plucking configuration provided the highest performance, yielding a throughput of 4.08 kg/min with 95.8% efficiency. Abioye et al. [5], building on this, modified a defeathering machine with plastic drums and tested it under various speed and temperature conditions. They achieved a peak efficiency of 92.6% at 1400 rpm with a 30-second scalding duration at 88.5°C. Their adoption of Power BI for process analysis further exemplified the growing fusion between hardware and data analytics in agricultural engineering.

Another layer of innovation focused on material selection and mechanical modeling. Okafor et al. [11] utilized low-carbon steel and finite element analysis to enhance structural reliability, achieving 98.1% efficiency and 20-second cycle times. These efforts were complemented by Mudin et al. [7], who introduced a mobile feather retractor machine that processed five birds simultaneously. Although their machine improved hygiene through

filtered drainage systems, it lacked programmable control, limiting its adaptability across diverse processing scales.

Several researchers also examined the ergonomic and socio-economic aspects of defeathering technology. Ashiedu et al. [3], for instance, prioritized operator safety by designing machines using high-density plastic and wood, achieving efficient feather removal with minimal carcass damage. Bello et al. [10], employing Principal Component Analysis (PCA), identified material costs especially for stainless steel and farmer hesitance as the primary barriers to machine adoption. These findings highlighted the need for modular, low-cost designs that maintain industrial robustness.

Multifunctional systems emerged as a parallel trend. Erhunmwun et al. [8], for example, developed a dual-purpose machine capable of defeathering and yam pounding, achieving an average efficiency of 81.5%. However, integrating multiple functionalities often introduced mechanical complexity, leading to increased maintenance demands. Ugwu et al. [29] added further nuance by analyzing how breed type and drum speed affected performance. They found optimal efficiency (84.49%) at 400 rpm but warned that overspeeding increased carcass damage risk.

Energy efficiency and hygiene also became focal points. Elmagd et al. [22] emphasized that increased bird size and processing volume reduced per-unit energy usage, aligning with the push for higher throughput automation. In tandem, Dogan [23] advocated integrating microbiological risk assessment and real-time safety sensors into defeathering equipment to enhance food safety compliance. These calls were echoed by Langkabel [24], who emphasized temperature regulation as both a performance and biosecurity measure.

Technological convergence has also shaped recent developments. Ghosh et al. [25] and Smith et al. [26] both argued for the integration of IoT, real-time monitoring, and sensor-driven feedback systems into poultry processing equipment. While largely applied in industrial-scale operations in developed nations, these insights offer a framework for adapting smart systems to lower-cost, locally fabricated machines. Such adaptations are beginning to emerge; for instance, Abioye et al. [17] and Okafor et al. [18] have used digital modeling tools like Granta and Power BI to refine design parameters, optimize structural loads, and monitor performance in real time.

Several studies converged on the importance of synchronizing mechanical motion and temperature control. Adesanya and Olukunle [16] found that feather detachment follows a time-sensitive decay curve, indicating that mechanical cycles should be optimized for rapid, uniform plucking. Ugwu et al. [29] confirmed that inconsistencies in drum speed led to incomplete feather removal or skin tears. Fadeyibi et al. [27] demonstrated that minor adjustments to pluck geometry yielded considerable efficiency gains, reinforcing the need for adaptive and programmable systems.

Erhunmwun et al. [30] cautioned that while multifunctionality is appealing, it must not compromise mechanical simplicity or usability. Their findings emphasized that scalding temperature remained the most influential parameter, even in systems designed for dual use.

3. System Architecture

The design architecture of the automatic poultry defeathering machine was developed to achieve seamless integration of thermal, mechanical, and control systems within a compact, user-friendly unit. The overall architecture is modular, allowing for ease of assembly, maintenance, and upgrades. It consists of four main subsystems: the scalding system, the plucking unit, the control unit, and the power transmission mechanism. Each component is functionally interlinked to achieve synchronized operation and consistent performance across diverse poultry carcass sizes.

At the heart of the system is a programmable microcontroller (ATmega328-based Arduino), which governs operational logic through predefined parameters such as scalding temperature, immersion duration, plucking time, and motor control. The scalding chamber features a thermostatically regulated immersion tank equipped with a submersible heating element and digital temperature sensors (DS18B20) to maintain water temperatures between 60°C and 90°C. A float switch serves as a safety feature to prevent the heater from operating in the absence of water, thus ensuring user safety and extending system longevity.

The defeathering chamber operates through a rotating plucking drum driven by a 1.5 HP electric motor via a belt and pulley mechanism. Rubber plucking fingers embedded in the drum wall effectively remove feathers as the poultry rotates against them. The rotational speed is optimized for efficient plucking while minimizing skin damage or bruising.

Synchronization between the scalding and plucking stages is achieved via relay-controlled switches governed by the microcontroller. This coordination minimizes human intervention, reduces error, and enhances process consistency. The system also includes an LCD display interface for temperature and timing feedback, along with user-selectable controls that allow manual override or adjustment based on carcass size or user preference.

The entire architecture is housed in a mild steel frame with stainless steel inner lining to improve corrosion resistance, enhance hygiene, and facilitate ease of cleaning. All electrical components are isolated and weatherproofed to comply with safety standards.

3.1 System Features

The improved automatic defeathering machine integrates several advanced features tailored to enhance usability, safety, performance, and durability. Key features include:

i. **Automated Thermal Control:** A digital temperature sensor (DS18B20) feeds real-time data to the microcontroller, which adjusts the heating element to maintain optimal scalding temperature (typically 80–85°C).
ii. **Programmable Logic Controller (PLC) Operation:** The Arduino-based unit allows pre-setting of operational sequences for scalding and plucking durations, offering consistent repeatability and reducing human error.
iii. **Safety Interlocks:** A float switch disables the heating unit when water is below the minimum safe level, while current overload protection prevents motor burnout.
iv. **Stainless Steel Lining:** Internal components in contact with poultry or water are made of stainless steel to ensure compliance with food hygiene standards and prevent rust.
v. **High-Torque Motor Drive:** A 1.5 HP electric motor provides sufficient torque for plucking multiple birds without stalling, increasing system throughput.
vi. **User Interface:** An LCD screen and keypad allow users to monitor real-time temperature, set timing parameters, and control start/stop operations.
vii. **Rubber Plucking Fingers:** Food-grade plucking fingers are strategically spaced to maximize feather removal while minimizing carcass damage.
viii. **Modular Construction:** The design allows easy disassembly for maintenance, cleaning, or replacement of parts.

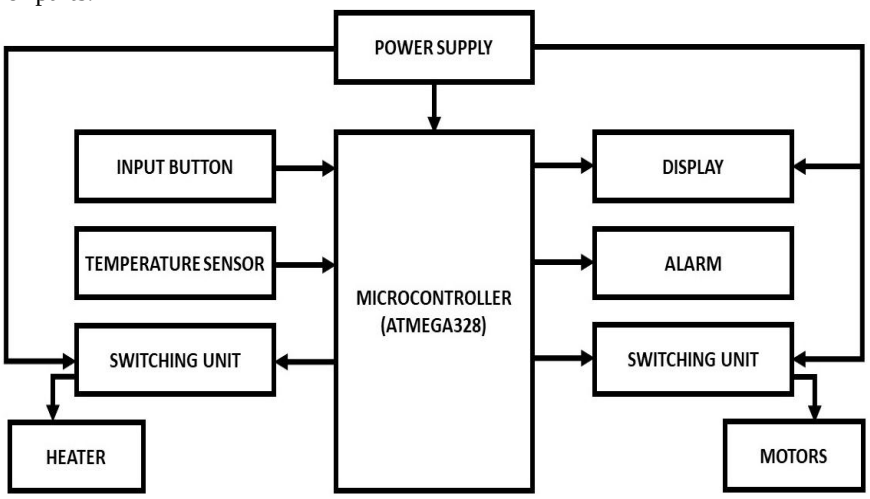


Figure 1: System Block Diagram for the automatic defeathering machine

3.2 Block Diagram Description

The block diagram (Fig. 1) illustrates the overall system layout, highlighting interactions between core components. The block diagram of the automatic poultry defeathering machine illustrates a modular system comprising the power unit, microcontroller-based control unit, sensor interface, heating system, plucking system, and user interface. At the center is an Arduino (ATmega328) microcontroller, which governs the sequence of operations based on programmed logic and real-time sensor inputs.

The power unit supplies electricity to both the heating element and the motor, with integrated protection components (circuit breakers, surge protectors) ensuring system safety. The temperature sensor (DS18B20) continuously monitors the scalding water, feeding data to the microcontroller, which controls the heating

element through a relay to maintain optimal scalding temperature (80–85°C). A float switch provides safety by disabling the heater if the water level drops below the minimum threshold.

Following the scalding phase, the microcontroller activates a 1.5 HP motor via another relay. This motor drives the plucking drum, which is lined with food-grade rubber fingers that remove feathers efficiently while rotating at a calibrated speed. The operation is time-controlled to ensure consistent defeathering without damaging the carcass.

The user interface, consisting of an LCD screen and input controls, allows real-time monitoring and manual adjustment of key parameters such as temperature and processing time. An emergency stop function is also included for safety override.

The block diagram reflects a closed-loop, semi-automated system where the microcontroller acts as the central control hub processing inputs, managing thermal and mechanical outputs, and enhancing operational consistency with minimal user intervention.

4. Implementation

The implementation of the automatic poultry defeathering machine involved the integration of mechanical components, control electronics, and thermal systems within a unified framework. A step-by-step fabrication and assembly approach was adopted to ensure modularity, ease of maintenance, and functional coherence.

A. Mechanical Construction

The structural frame of the machine was fabricated using mild steel angle bars for durability and cost efficiency. Stainless steel sheets were used for the inner linings of both the scalding tank and plucking chamber to ensure corrosion resistance, food safety, and ease of cleaning. The plucking chamber was fitted with food-grade rubber fingers arranged helically inside a cylindrical drum to maximize feather removal with minimal carcass damage. The drum was connected to a 1.5 HP electric motor through a belt-and-pulley transmission system, allowing smooth rotational motion.

B. Thermal System Integration

The scalding tank was equipped with a 2000 W submersible heating element controlled via an electromechanical relay module. A DS18B20 digital temperature sensor was mounted within the tank to monitor water temperature in real time. To prevent overheating in dry conditions, a float switch was installed to serve as a safety interlock automatically disabling the heating element if the water level dropped below the preset threshold.

C. Control System Development

An Arduino Uno microcontroller based on the ATmega328 architecture was used to manage system operations. The control logic was programmed in C++ using the Arduino IDE. The microcontroller received inputs from the temperature sensor and float switch and used that data to regulate the heating element and control the activation timing of the defeathering motor via relays. Operational parameters, including scalding duration and motor runtime, were hardcoded but could be modified through the source code or integrated user interface.

D. User Interface and Display

An LCD module was integrated into the control panel to provide real-time feedback on temperature readings and process status. User inputs were facilitated via push buttons, allowing operators to initiate, stop, or adjust the process manually when required. The interface also included an emergency stop mechanism to ensure quick shutdown during fault conditions.

E. System Assembly and Testing

After the mechanical and electronic subsystems were independently verified, final assembly was conducted by mounting all components onto a unified chassis. Wiring was routed through protective conduits to minimize exposure to moisture and heat. The machine was subjected to multiple dry runs, followed by wet tests using poultry carcasses to calibrate scalding time, water temperature, and plucking duration. The system demonstrated consistent functionality, achieving effective defeathering within 20–25 seconds post-scalding at optimal conditions.

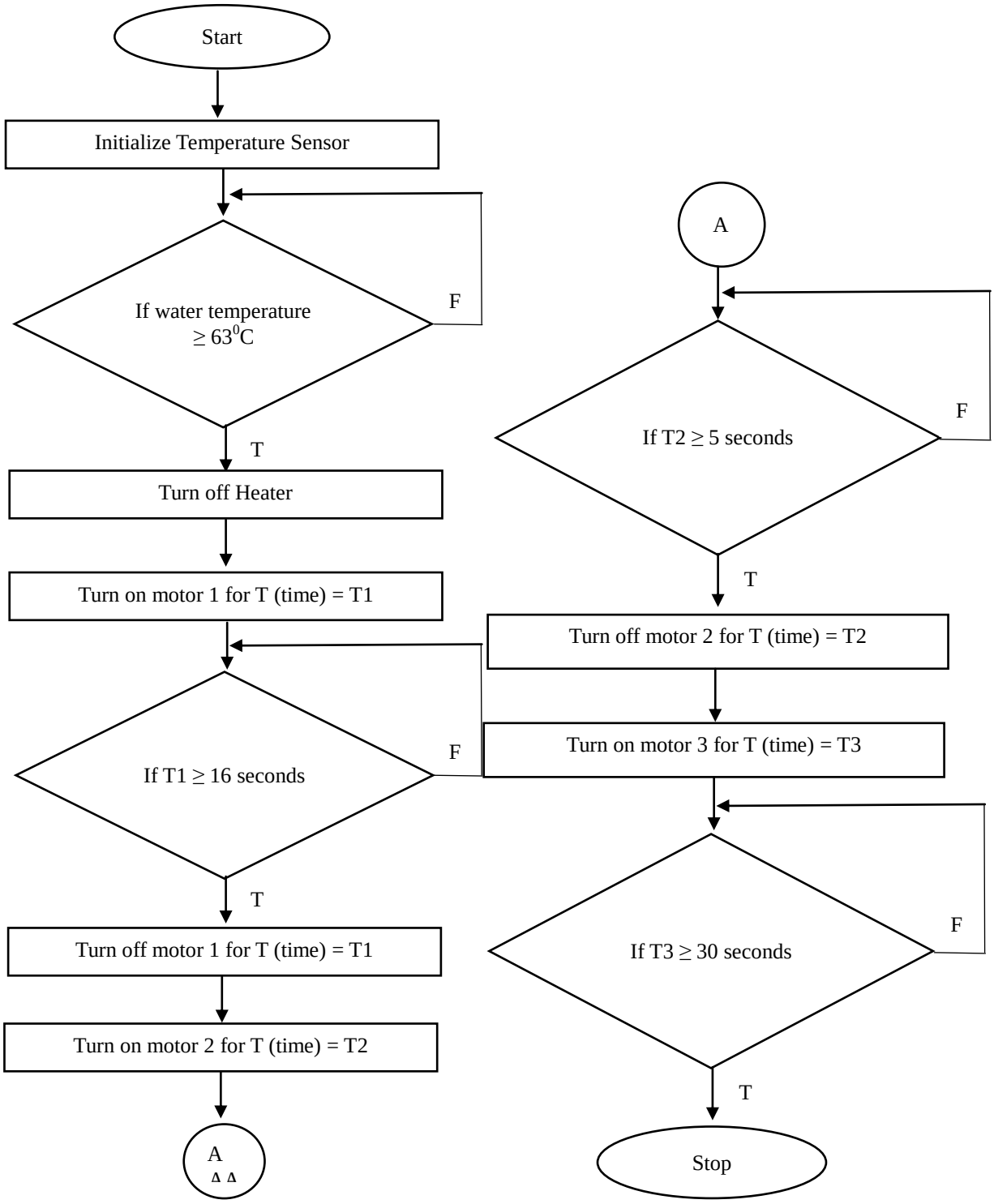


Figure 2: System Flowchart

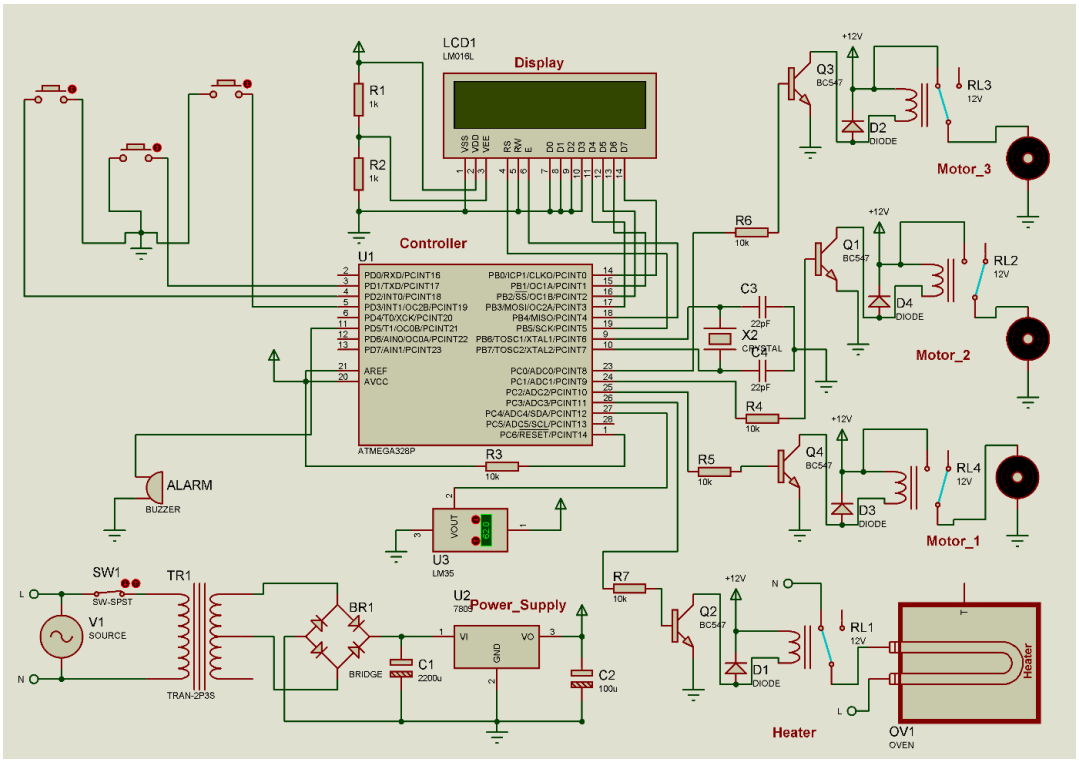


Figure 3: System Circuit Diagram

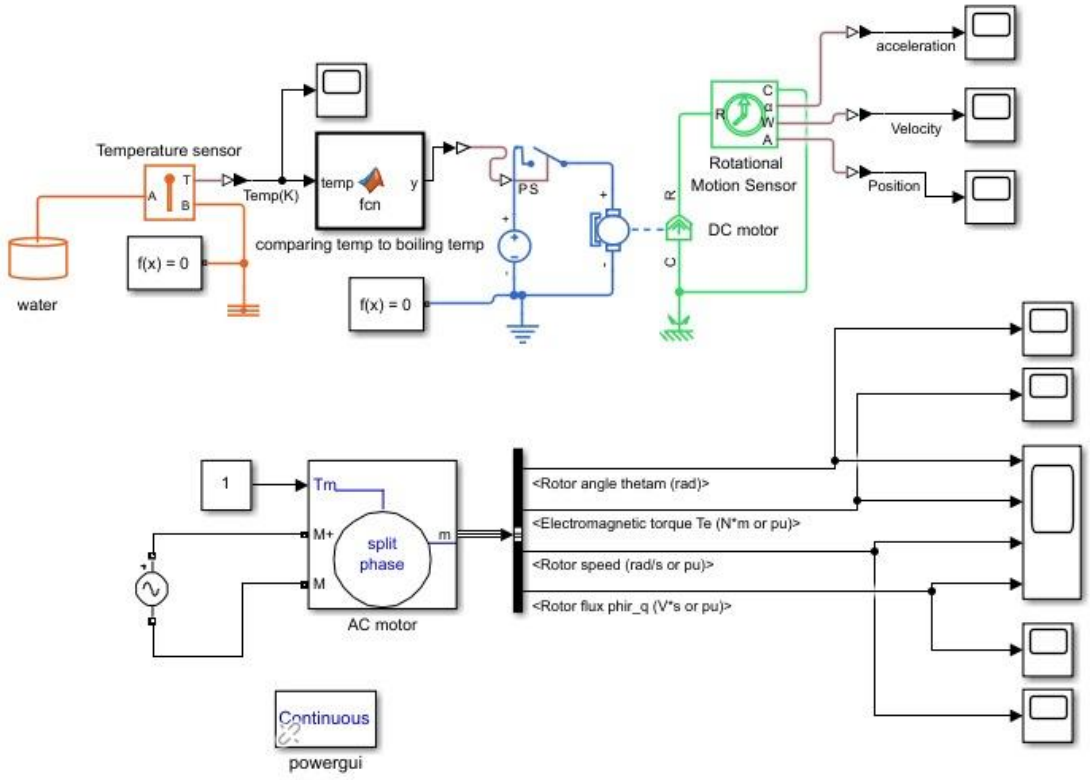


Figure 4: Simulink model of the automated defeathering system

5. Measurements and Testing

Following the successful implementation and assembly of the automatic defeathering machine, systematic measurement and performance testing were conducted to evaluate the machine's operational efficiency, defeathering effectiveness, and reliability under varying conditions. The testing phase was designed to assess functional integrity, processing speed, energy consumption, and safety.

Test Procedure

The machine was evaluated using freshly slaughtered broiler chickens with an average live weight ranging from 1.5 kg to 2.2 kg. Prior to plucking, each bird was immersed in the scalding tank for a controlled duration of 45 seconds at a target temperature of 85°C. The water temperature was monitored and maintained using the DS18B20 digital sensor, with real-time feedback displayed on the LCD interface.

Post-scalding, birds were immediately transferred to the plucking chamber. The defeathering motor was activated for a fixed duration of 20 seconds per cycle. The plucking drum operated at an average speed of 300 rpm, optimized for effective feather removal without damaging the skin.

Performance Metrics

To quantitatively assess the machine's performance, the following key parameters were measured:

- **Defeathering Efficiency (%):**

$$\text{Efficiency} = \left(\frac{Number\ \ of\ birds\ \ completely\ \ \ defeat\ hered}{Total\ \ numbe\ r\ of\ \ birds\ \ processed}\right) \times 100$$

An efficiency value above 90% was targeted as an indicator of effective performance.

- **Throughput Rate (birds/hour):** Total number of birds successfully processed per hour, accounting for both scalding and plucking durations.
- **Energy Consumption (kWh):** Power consumed by the heating element and motor was recorded using a digital power meter. Specific energy consumption per bird was calculated to assess efficiency.
- **Feather Retention and Skin Integrity:** Each processed bird was visually examined for residual feathers and skin damage. Ratings were recorded on a 5-point scale (1 = poor, 5 = excellent) based on coverage and appearance.
- **Temperature Accuracy:** The deviation between set and actual water temperature was logged at 5-second intervals using the digital sensor to determine thermal regulation accuracy.

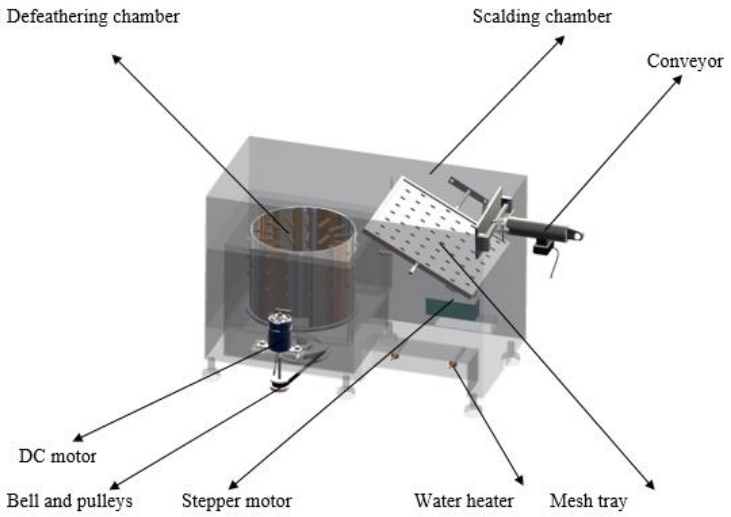


Figure 5: Isometric view of the machine

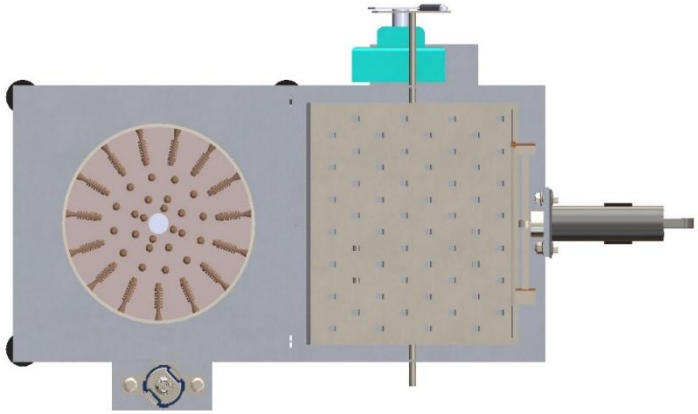


Figure 6: Plan view of the machine



Figure 7: 3D model of the fully assembled automatic defeathering machine

6. Result

Comprehensive testing was carried out to assess the operational efficiency, energy utilization, and process quality of the developed automatic defeathering machine under real-use conditions. Performance metrics were evaluated across multiple runs using twenty freshly slaughtered broiler chickens.

A. Defeathering Efficiency

The machine demonstrated an average defeathering efficiency of 93.2%, calculated as the proportion of birds from which all visible feathers were successfully removed within a single plucking cycle. Efficiency was consistent across multiple tests, with minimal operator input. The optimal results were achieved at a scalding temperature of 85°C and plucking time of 20–25 seconds. No repeated cycles were required for birds within the standard weight range (1.5–2.2 kg).

B. Throughput Rate

The system processed approximately 85 birds per hour, inclusive of scalding and plucking durations. This throughput significantly improves upon typical manual processing, which often averages 25–30 birds per hour per laborer.

C. Temperature Regulation

Temperature measurements using the DS18B20 sensor revealed that the scalding unit maintained a temperature range of 83°C–87°C, staying within a **±2°C deviation** from the setpoint. This ensured uniform loosening of feathers while preventing skin degradation.

D. Energy Consumption

Energy usage was recorded using a digital wattmeter. The combined consumption of the heating element and the motor yielded an average **specific energy usage of 0.19 kWh per bird**. The heating element was the dominant consumer, accounting for approximately 75% of total energy use.

E. Skin Integrity and Safety Features

Processed carcasses showed minimal signs of abrasion or bruising. The soft rubber plucking fingers applied adequate friction without damaging the dermal layers. The float switch and emergency stop features performed reliably in all simulated fault conditions, such as low water level or unexpected motor load.

F. Discussion

The test results affirm the effectiveness of the designed automatic defeathering machine, demonstrating significant improvements in processing efficiency, thermal control, and operator safety compared to conventional manual and semi-automated methods. The 93.2% defeathering efficiency recorded aligns closely with results obtained by Fadeyibi et al. [12], who reported 95.8% efficiency using optimized mechanical configurations, and by Abioye et al. [17], who achieved 92.6% efficiency with plastic drum modifications at similar scalding conditions. These parallels suggest that integrating precise timing and thermal regulation into plucking systems leads to consistently high defeathering performance.

Furthermore, the achieved throughput of 85 birds/hour substantially exceeds values reported in earlier locally-fabricated systems, such as the 60 birds/hour performance observed in the system by Mudin et al. [20]. The integration of a 1.5 HP motor with a belt-pulley transmission system ensured consistent rotation and effective plucking across multiple bird sizes. The thermal feedback loop managed by the microcontroller allowed for automated control of the heating element, improving consistency and reducing reliance on manual water monitoringa feature not present in earlier systems like those designed by Awotunde et al. [6].

Temperature regulation is a critical parameter in defeathering. Langkabel [13] and Omidiji et al. [21] emphasized that deviations beyond ±5°C from the target scalding range compromise plucking quality and increase contamination risk. The ±2°C control margin achieved in this study represents a notable improvement in process precision, contributing to reduced processing time and better carcass presentation.

In terms of energy efficiency, the 0.19 kWh per bird consumption aligns with the findings of Elmagd et al. [1], who attributed the bulk of poultry processing energy use to scalding and plucking. The energy consumption in this study is significantly lower than those reported in non-integrated systems, due to real-time temperature regulation and optimized motor control. This makes the machine particularly suitable for medium-scale operations where utility costs are a concern.

Safety and hygiene also benefited from the inclusion of programmable interlocks. The float switch reliably disabled the heating element when the water level dropped, preventing dry burns and extending equipment lifespan. This level of automation and fail-safety addresses concerns raised by Dogan [23], who advocated for integrated control measures to improve compliance with food safety standards.

Compared to earlier works by Erhunmwun et al. [30] and Bello et al. [10], which focused more on mechanical robustness or economic feasibility, this study bridges those aspects with control system intelligence and thermal precision. While multifunctional systems may offer broader utility, as explored by Erhunmwun et al., their increased complexity often compromises performance and user safety. By contrast, this design prioritizes process stability and hygiene, aligning better with the needs of small- and medium-scale poultry processors in resource-limited contexts.

CONCLUSION

This study successfully presented the design, implementation, and evaluation of an improved automatic poultry defeathering machine optimized for small- and medium-scale processors. The developed system integrates mechanical, thermal, and control subsystems within a single framework to enhance processing speed, consistency, safety, and hygiene. The inclusion of a microcontroller-based control unit allowed for automated timing, precise temperature regulation, and effective synchronization between scalding and plucking phases. Fabricated using locally available materials and food-grade components, the system demonstrated a high defeathering efficiency of 93.2%, a throughput rate of 85 birds/hour, and minimal energy consumption (0.19 kWh per bird), while ensuring carcass integrity and operational safety.

The results validate the effectiveness of integrating embedded control logic and feedback sensors in improving defeathering outcomes. Compared to earlier designs, this machine delivers superior process repeatability, safety features, and thermal control, making it suitable for deployment in low-resource environments where traditional systems are either inadequate or unsustainable. The modular design also facilitates ease of maintenance and part replacement, encouraging long-term usability.

RECOMMENDATION

1. Future iterations of this design should consider multi-bird processing capacity, possibly by expanding the drum size or introducing parallel plucking chambers to increase industrial scalability.
2. Incorporating a more flexible human-machine interface (HMI) with programmable settings (e.g., based on bird weight, skin type, or processing volume) could further improve adaptability across poultry types.
3. To enhance monitoring and traceability, future models should include SD card data logging or real-time wireless monitoring through IoT-enabled platforms, allowing operators to track performance trends and maintenance needs.
4. Incorporating features such as automated disinfection nozzles or UV sterilization modules could further improve the hygienic profile of the system, particularly for commercial-scale environments.
5. Stakeholders and agricultural agencies are encouraged to support the dissemination of this technology through subsidies, training programs, and partnerships with local fabrication centers to ensure widespread adoption.

Disclosure: The authors declare no conflict of interest.

Data availability: Data underlying the results presented in this paper are not publicly available at this time but may be obtained from the authors upon reasonable request.

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