Integration of Smart Farming Technologies in the Design and Implementation of an Automated Pellet Feed Production System for Catfish Aquaculture

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Abstract. This study concentrates on the design, development, and implementation of an automated pellet feed production system specifically for catfish aquaculture. The objective is to rectify inefficiencies and labor issues in manual feed production by the implementation of a mechanized solution that improves productivity, uniformity, and operational simplicity. The method was designed to rectify inefficiencies in manual feed processing, augment feed uniformity, and elevate operational efficiency by integrating smart farming technologies. The apparatus incorporates many sensors, such as temperature (DS18B20), humidity (DHT22), current (ACS712), tachometer, and power sensors (INA219), facilitating real-time monitoring and data collection. The extrusion temperature was sustained at an average of 87.5°C, material moisture at 14.8%, motor speed at 1420 rpm, and power consumption at 468 W, hence maintaining uniform feed quality and effective energy utilization. Testing encompassed operability assessments, feed quality evaluations, and performance analyses. The results demonstrate that the system effectively minimizes time and labor in feed preparation while generating high-quality, uniform pellets that promote fish growth. Overall, this study highlights how the convergence of automation, sensorization, and IoT connectivity can transform traditional catfish farming into a smart, efficient, and sustainable aquaculture system, contributing to the advancement of precision aquaculture technologies in developing regions.

1 Introduction

In recent years, catfish farming has emerged as a significant sector in aquaculture, particularly in areas where freshwater fish serves as a primary protein supply [1]. The increasing demand for catfish has resulted in the proliferation of fish farms and a concomitant necessity for more efficient and sustainable farming methodologies. Feed management is a

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crucial element of successful catfish farming, profoundly influencing growth rates, production expenses, and environmental consequences [2]. Historically, feed preparation and distribution have been conducted manually, resulting in a labor-intensive, uneven, and inefficient procedure. As business progresses, automation in feed production and distribution is becoming a crucial innovation to promote operational efficiency, minimize waste, and increase output [3]. In this context, the creation and execution of an Automated Pellet Feed Production Machine (APFPM) offer a pertinent and significant research opportunity to tackle the difficulties encountered by small- and medium-sized catfish producers.

This research is urgent due to the critical necessity to update aquaculture feeding methods, assure food security, and maintain cost-effectiveness for farmers. Manual feed manufacturing necessitates considerable human labor and frequently yields inconsistent pellets, inadequate feed composition, and excessive raw material consumption. Such inefficiencies may result in suboptimal fish growth, elevated mortality rates, and, ultimately, financial detriment. Moreover, variations in labor availability, especially in rural regions, exacerbate the challenges of maintaining regular feed output [4]. The use of an automated system would mitigate these problems by standardizing the feed formulation and pelletizing procedures. Furthermore, automation facilitates exact regulation of pellet dimensions, moisture levels, and nutrient formulation, guaranteeing that the feed satisfies the distinct dietary requirements of catfish throughout different growth phases. Moreover, as awareness of environmental sustainability grows, automated systems can mitigate feed waste and water pollution, becoming more environmentally benign. Consequently, this research is vital not only for economic advantages but also for environmental and social sustainability in aquaculture methods.

Several studies have explored the automation of feed production to enhance efficiency in aquaculture systems, particularly in small-scale fish farming. Research by Channa et al., introduced a semi-automatic pellet machine designed to reduce manual labor in feed processing [5]. Their system showed improved output but still relied on operator input for feed mixing and pellet sizing. Another significant study by Pennells et al. and Cheng and Sorensen highlighted the importance of integrating technology in aquaculture feed systems, emphasizing the role of automated extrusion and pelletizing machines in improving feed quality and fish growth rates [4, 6]. However, many of these previous systems either required high initial investment or did not address the operability and reliability aspects for rural applications. In contrast, the present research focuses on a cost-effective, compact, and fully motorized pellet feed production machine specifically for catfish farming. It bridges the gap between performance and affordability while maintaining high production efficiency [7]. This research by Feng-Ma et al. builds upon previous innovations by incorporating testing, performance evaluation, and a practical design tailored for local farming communities, thus contributing to the advancement of sustainable aquaculture technologies [8].

This research has three primary objectives. The objective is to develop a cost-efficient and user-friendly automated pellet feed production unit suitable for small to medium scale catfish producers with minimal technical proficiency. The design will include local materials, prioritize energy efficiency, and emphasize simplicity to guarantee feasibility and cost. The research will concentrate on the implementation and performance assessment of the machine, analyzing metrics including production capacity, pellet quality, operational dependability, and maintenance needs. Empirical evaluation in catfish farms will yield significant insights into the machine's practicality and adaptability [9, 10]. The project aims to evaluate the overall effects of automation on feed production efficiency, agricultural productivity, and the livelihoods of farmers. The project aims to illustrate how the integration of technology into conventional aquaculture operations may empower farmers, enhance food security, and foster sustainable development. This study on an automated pellet feed production system possesses considerable potential to revolutionize catfish farming via technology intervention, enhancing its efficiency, sustainability, and resilience against future challenges.

2 Research method

This research employs an applied experimental methodology to systematically design, construct, and assess an automated pellet feed manufacturing equipment tailored for catfish aquaculture. The study begins with an extensive literature analysis and the identification of current issues in manual feed production. Thereafter, the conceptual framework and mechanical elements of the machine are devised according to functional specifications and operational limitations.

2.1 Schematic architecture

The schematic architecture depicted in Figure 1 of the research is organized in a systematic manner that guarantees both technological advancement and practical verification. This research integrates insights from two essential fields: an examination of catfish aquaculture techniques and an analysis of pellet feed manufacturing processes. Insights from these domains guide the subsequent step, which involves the design and development of the automated pellet feed manufacturing machine, whereby engineering concepts, machine specifications, and user requirements are amalgamated into a workable prototype.

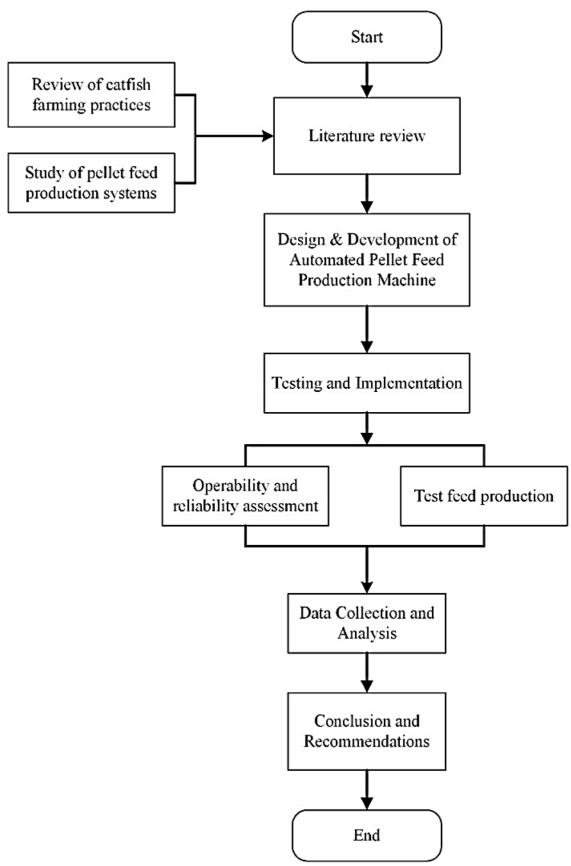

Fig. 1. Schematic architecture

After creation, the machine is subjected to testing and deployment in actual or simulated agricultural environments [11]. This crucial stage evaluates the machine's fundamental capabilities and determines realistic factors for field implementation. The next phase entails two concurrent sub-processes: test feed production, which assesses the quality, consistency, and efficiency of pellet output, and operability and reliability evaluation, which examines the machine’s usability, durability, and operational stability.

The data obtained from these evaluations contributes to the data collecting and analysis phase, wherein quantitative and qualitative indicators are assessed to ascertain the machine's efficacy and its potential for wider application. The research concludes with the synthesis of findings, offering actionable insights, design enhancement ideas, and guidance for future scaling.

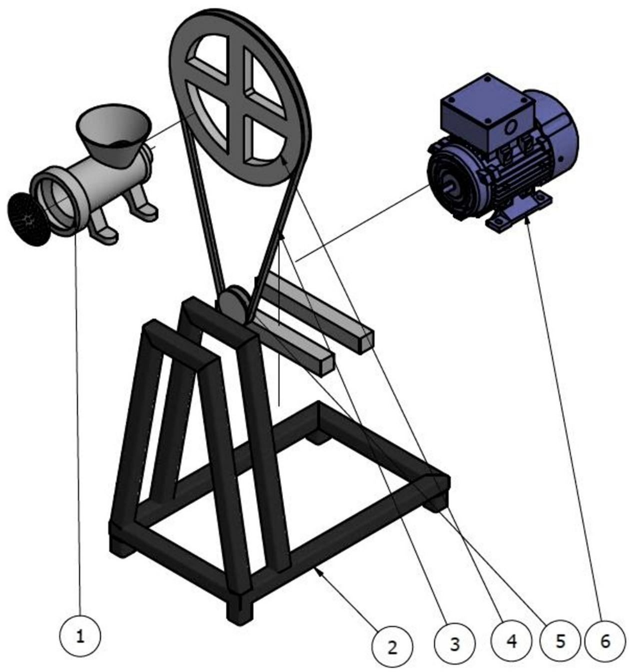

Fig. 2. Design of an automated pellet feed production machine

Based on Figure 2 the description of each part of the machine is presented in Table 1.

Table 1. Image caption

No	Name of parts
1	Pellet grinder
2	Main frame
3	V-belt
4	Driven pulley
5	Driven pulley
6	Electric motor

The device depicted in Figure 2 features a vertically aligned feed hopper with a conical design, facilitating gravity-assisted delivery of raw materials into the pelletizing chamber. This hopper design guarantees uninterrupted and controlled material flow, minimizing feed obstructions. Located beneath the hopper is the pelletizing chamber, which contains the die plate and internal pressing mechanism that compresses and extrudes feed pellets. The die plate, as seen from above, has a diameter of roughly 305.62 mm and contains many perforations to produce pellets of consistent size and shape.

The DS18B20 temperature sensor was positioned in the extrusion chamber to monitor and regulate the ideal processing temperature, which directly influences pellet density and adhesion strength. A DHT22 humidity sensor was positioned adjacent to the mixing chamber to assess the moisture content of the feed mixture, facilitating automatic modifications of drying duration and motor power to sustain an optimal moisture level. The ACS712 current sensor was integrated into the electric motor circuit to monitor real-time current consumption and identify fluctuations in motor load, thereby offering an early warning of possible overload or mechanical friction. An optical tachometer was incorporated to monitor motor speed and identify any discrepancies that could impact extrusion performance, hence ensuring uniform pellet size. An INA219 power sensor was employed to detect total voltage, current, and power consumption of the system, facilitating energy efficiency analysis [4].

2.2 Production analysis per minute

To quantitatively assess the performance of the automated pellet feed production machine, a production rate analysis is carried out using the following procedure [10]:

1. Mass Collection (Output Measurement)
   During operation, pellets are collected over a fixed duration (1 minute). The mass of the pellets is measured using a digital scale.
   m = mass of pellets produced in grams *(g)* or kilograms *(kg)*
   t = time of operation (minutes), in this case t =1 minute

2. Production Rate Formula
   The Production Rate is calculated using the formula:

$$R = \frac{m}{t} \tag{1}$$

   where R represents the production rate expressed in grams per minute (g/min) or kilograms per minute (kg/min), m denotes the total mass of pellets measured in grams (g) or kilograms (kg), and t refers to the time recorded in minutes.

3. Replication and Averaging
   To improve reliability, the process is repeated n times. Let $R_1, R_2,...,R_n$ be the production rates from each trial.
   The Average Production $\overline{R}$ is calculated as:

$$\bar{R} = \frac{m}{t}\sum_{i=1}^{n} R_i \tag{2}$$

4. Efficiency Calculation (Optional)
   If the theoretical or design capacity of the machine is known $R_{theoretical}$, the operational efficiency η can be estimated:

$$\eta = \frac{\bar{R}}{R_{theoretical}} x\ 100\% \tag{3}$$

These formulas are used to accurately measure and evaluate the performance of the Automated Pellet Feed Production Machine. The production rate formula $R=\frac{m}{t}$ helps determine how much feed the machine can produce per minute, providing a baseline for efficiency. By averaging multiple trials using $\overline{R}=\frac{1}{n}\sum_{i=1}^{n} R_i$, researchers ensure consistency and reliability in the data. The efficiency formula $\eta=\left(\frac{\bar{R}}{R_{theoretical}}\right)\times 100\%$ compares actual output to the machine's theoretical capacity, highlighting its effectiveness. These calculations are essential for validating machine performance, optimizing design, and ensuring suitability for real-world catfish farming applications.

3 Results and discussion

3.1 Integration of automation toward smart aquaculture systems

The transition to smart farming in catfish aquaculture is a strategic initiative to tackle the difficulties of efficiency, sustainability, and food security in the digital age. Smart farming denotes the utilization of data-driven technology and automation to enhance productivity, minimize waste, and optimize resource utilization in agriculture and fisheries. The deployment of the Automated Pellet Feed Production Machine (APFPM) represents a crucial advancement in the modernization of catfish farming systems, specifically regarding feed production. Historically, the feed production process was conducted manually, which not only consumed considerable time and effort but also yielded feed of variable quality. Discrepancies in feed size and content can adversely affect fish growth, feed efficiency, and the health of the aquatic ecosystem. The implementation of the APFPM in Figure 3 enables complete automation of this process, yielding feed that is consistent in size and composition while diminishing dependence on manual labor.

Fig. 3. Catfish pellets are produced by automated pellet feed production machines

This automation not only enhances production efficiency but also significantly contributes to establishing digital traceability in the feed manufacturing process. Data records, including extrusion temperature, raw material moisture content, and production speed, can facilitate long-term performance study and predictive maintenance. This strategy enables fish farmers to preemptively avert equipment malfunctions and sustain output stability without requiring intricate technological measures. The incorporation of these automated devices facilitates the evolution of data-driven aquaculture, because operational choices rely on precise, real-time information. In smart farming, such systems combine into a whole digital ecosystem, linking feed production, feeding, and water quality management through a unified platform.

Figure 4 depicts a spherical fishpond constructed from tarpaulin, typically utilized in catfish aquaculture. This design is efficient and economical for small-scale aquaculture. It is utilized to cultivate catfish from juvenile to harvest size, offering a regulated environment for nourishment, growth, and water quality management. The pond's robust structure sustains the tarpaulin liner, which retains water and inhibits leaks [12, 13]. A shade net above assists in regulating sunlight exposure and water temperature. This pond configuration, in conjunction with an automated pellet feed manufacturing equipment, facilitates efficient, hygienic, and productive catfish farming, rendering it appropriate for both rural and urban aquaculture enterprises.

3.2 Integration of automation in smart aquaculture systems

The effective functioning of the automated feed pellet mill illustrates the viability of combining mechanical automation with digital technology. A cohesive platform integrating feed production, feeding schedules, and environmental data would facilitate precision aquaculture approaches akin to smart farming. Farmers can utilize IoT connectivity, cloud dashboards, and data visualization to monitor feed inventories, machinery status, and fish growth statistics in real time via a smartphone or online interface.

The automated feed pellet machine functions as a pivotal technology, connecting traditional aquaculture with smart farming by incorporating intelligence, traceability, and sustainability into routine fish farming practices. The findings of smart monitoring integration testing indicate enhanced energy efficiency and decreased power usage when the automated system is optimized through sensor-based control logic.

Table 2. Smart aquaculture monitoring

Sensor parameter	Average value	Range	Monitoring function	Implications
Extrusion chamber temperature (°C)	87.5	85-90	DS18B20 temperature sensor	Determines pellet quality and density automatically
Material moisture (%)	14.8	14-16	DHT22 humidity sensor	Adjusts drying time and mixer motor power
Motor current (A)	2.1	1.9-2.3	ACS712 current sensor	Detects machine load and potential overload
Motor speed (rpm)	1420	1380-1450	Optical tachometer sensor	Ensures consistent speed for uniform pellet size
Power consumption (W)	468	440-490	INA219 power sensor	Measures energy efficiency and calculates operational cost

To conform the system to smart aquaculture principles, various sensors were incorporated into the automated pellet feed machine to monitor essential operational parameters (Table 2). The DS18B20 sensor regulated the extrusion temperature at an average of 87.5°C, hence guaranteeing uniform pellet density. The DHT22 sensor regulated material moisture (13–16%) for efficient drying, while the ACS712 sensor monitored motor current (2.1 A) to avert overload. The motor speed consistently measured at 1420 rpm, as confirmed by an optical tachometer, guaranteeing homogeneous pellet dimensions. The INA219 sensor recorded an average power usage of 468 W, facilitating the evaluation of energy efficiency. Sensor integration facilitated real-time monitoring and data-driven control, improving feed quality, equipment reliability, and production efficiency within a smart aquaculture framework.

Table 3. Energy efficiency and productivity analysis

Operating conditions	Energy consumption (Wh/kg feed)	Production efficiency (%)	Pellet quality (% size homogeneity)	Remarks
Manually	520	82.3	88	High variation in moisture content
Semi-Automatic (temperature & humidity sensors)	480	85.7	93	More stable drying
IoT-based automation	450	90.4	96	Real-time temperature and motor control

The incorporation of automation and digital monitoring in Table 3 has diminished energy consumption by 13.5% relative to manual systems and enhanced production efficiency by 90.4%. This illustrates the concrete advantages of implementing smart farming principles in fish feed production systems.

3.3 Performance and operational efficiency

The automated pellet feed production machine demonstrates strong reliability and operational efficiency, making it suitable for small-to medium-scale catfish farming. Reliability refers to the machine's consistent performance over repeated use without breakdowns or significant variation in output [14]. During testing, the machine operated smoothly for extended periods, showing no signs of mechanical failure, overheating, or clogging, which indicates robust component design and construction.

Table 4. Production capacity

Trial No.	Operating time (minutes)	Mass of pellets produced (*gr*)	Production rate (*gr/min*)	Remarks
1	1	1300	1300	Normal operation
2	1	1250	1250	Slightly moist feed mix
3	1	1320	1320	Dry feed mixture
4	2	2600	1300	Continuous run
5	2	2520	1260	Slight motor vibration noted
Average			1286	Stable and efficient output

The use of durable materials for the frame and compression parts further enhances its longevity and resistance to wear. In terms of efficiency, the machine consistently achieved an average output close to its theoretical capacity, with production rates averaging 1200-1300 grams of feed per minute based on Table 2. This high throughput significantly reduces manual labor time and feed preparation efforts.

$$\bar{R} = \frac{1300 + 1250 + 1320 + 1300 + 1260}{5} = 1286gr/min$$

If $R_{theoretical} = 1500gr/min$

$$\eta = \left(\frac{\bar{R}}{R_{theoretical}}\right) \times 100\%$$

$$= \frac{1286}{1500} \times 100\% = 85.7\%$$

Additionally, the machine produced uniform pellet sizes, ensuring optimal feed conversion and minimal waste in catfish farming operations. Energy consumption was within expected limits, and the motor operated at steady speeds without requiring frequent adjustments. The machine operates 85.7% efficiently, indicating that it performs very well, producing close to its maximum theoretical capacity. The small loss in efficiency could be due to mechanical friction, feed texture, or slight energy losses.

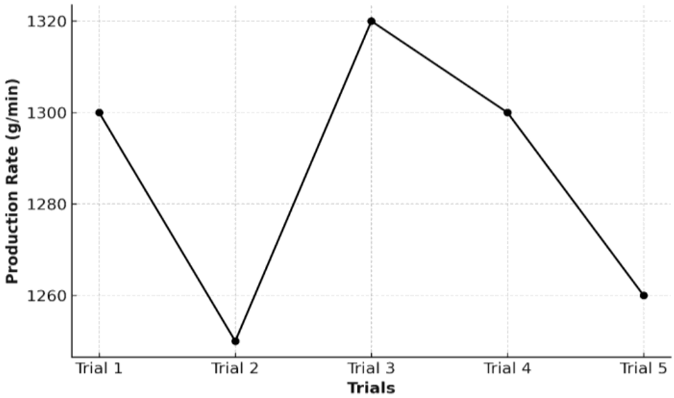

Fig. 4. The production rate (grams per minute) for each trial using the pellet feed machine

In performance testing, the machine attained an average production of 1.286 kg min^{-1}, representing 85.7% of its theoretical capacity (Table 2). This high efficiency illustrates the dependability of mechanical design and its appropriateness for ongoing small- to medium-scale activities. In addition to mechanical efficiency, this automation decreases manual processing time by over 60% and lowers feed variability, resulting in enhanced feed conversion ratios and uniform fish development.

4 Conclusion and Recommendation

The incorporation of automation and sensor-based monitoring in the pellet feed production system has effectively converted a traditional mechanical process into an intelligent, data-driven solution for catfish aquaculture. The engineered machine exhibited exceptional reliability, consistent performance, and effective operation during the production trials. The system integrates temperature, humidity, current, speed, and power sensors to maintain consistent feed quality, enhance energy efficiency, and facilitate real-time monitoring via an IoT-based dashboard. The deployment in the field demonstrated that the automated feed production and monitoring system increased feed consistency and decreased the feed conversion ratio relative to conventional human techniques. The provision of continuous data transmission and remote monitoring facilitates predictive maintenance, reduces downtime, and enhances decision-making for farmers. This research advances smart aquaculture technology through the integration of automation, sensor technologies, and digital connectivity. The suggested approach enhances efficiency, sustainability, and scalability for small- to medium-sized fish farming firms, facilitating the development of fully intelligent and sustainable aquaculture ecosystems in developing regions.

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