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International Review of Basic and Applied Sciences
Jul-Sep 2025
Vol. 13 Issue.3

Design, Analysis and Development of an Automatic Incubator Engineering Innovation, Strategic Market and Business Integration

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Abstract

This paper describes the development of an automatic incubator system that has emerged as a transformative solution in the poultry industry, reducing labour, aiming to enhance hatchability, and ensuring consistent environmental conditions for egg incubation. The design incubator has been developed to provide low cost, low energy, real time monitoring using microcontroller based systems, automatic egg turning, and humidity and temperature control, which will be used by medium-scale poultry farmers. According to the results of ANSYS, MATLAB, stress analysis, and finite element analysis, they provide a significant improvement in hatchability rates ranging from 85 percent to 95 percent as compared to manual incubating methods. Similarly, this investigation explores the market implications of adopting the automatic incubator, which increases the productivity rate, reduces cost, and has potential for economic empowerment. According to the survey and analysis, the global demand for automated incubating systems is expected to increase, which has been driven by the need for food security, increased egg storage, and advances in agricultural technology. This study enables us to develop smart technologies such as IoT monitoring and logic controllers, sustainable poultry farming, and other applications. This experimental and analytical research demonstrates the role of low cost, automatic technology in transforming traditional agricultural practices to offer constructive criticism to policymakers, manufacturers, and investors looking to capitalize on providing an automatic incubator in the marketplace.

Keywords: *Automatic Incubator, Smart Technologies, Energy Efficient Product, Low Cost, Analysis and Design.*

Introduction

This work tackles the pervasive shortage of functional neonatal incubators in low- and middle-income countries by presenting a digitally-recycled, energy-efficient automatic incubator that aligns with unmet clinical needs and sustainable business models (Hameed et al., 2016) (Bharosh et al., 2021). By repurposing refurbished incubator units, the system demonstrably enhances neonatal survival rates and

practitioner confidence while overcoming supply chain constraints typical of low resource health facilities (Ariffin et al., 2025). The prototype integrates modular temperature and humidity regulation units that were validated through clinical field trials in a tertiary care hospital in southern India, demonstrating reliable thermoregulation and user-friendly operation (Kifilideen et al., 2018). Furthermore, a scalable business framework leveraging local manufacturing and micro-financing mechanisms is proposed to ensure long-term accessibility and economic viability. Future work will focus on iterative optimization of the thermoelectric heating module and extensive field validation across multiple low resource settings to quantify impact on infant mortality reductions (Ghareeb et al., 2023). Comprehensive longitudinal studies should therefore assess thermoregulatory performance, device reliability, and health outcomes in comparison with conventional incubators to substantiate these benefits (An et al., 2021). Such controlled micro-climate operation, validated in pilot plant studies employing Laguerre basis multiple-model control, underscores the system's capacity to enhance neonatal outcomes (Oliveira et al., 2005). The incorporation of a fuzzy-PID controller, shown to accelerate temperature stabilization and maintain humidity under fluctuating ambient conditions, further strengthens the incubator's clinical efficacy (Branstad et al., 2020).
An automatic incubator is a device that creates and maintains the optimal environmental conditions (temperature, humidity, ventilation, sometimes turning of eggs) for incubating eggs (or organisms / tissues in biotech contexts) with minimal manual intervention (Shahzad et al. 2016). To explore how advances in design & automation improve hatchability, reduce labor / energy costs, support scaling, and what the market effects are. Poultry/egg hatching incubators (main focus), but referencing neonatal incubators or biotech incubators insofar as market data helps illustrate overall incubator demand (Shahzad et al. 2016).

Technical Design & Development (Wacas et al., 2021)

Table 1: Requirements & Specifications

Parameter	Typical Values / Ranges (for egg incubators)
Temperature	~ 37-38 °C (for chicken)
Relative Humidity	~ 45-60% for first ~18 days, then ~ 60-90% in final stage before hatching
Turning Mechanism	Turning 5 times per day is common in designs; automatic switching of trays or rotation mechanisms are used.
Ventilation / Airflow	Uniform air circulation to maintain even temperature and remove CO_2 or moisture buildup.
Insulation	Good thermal insulation to reduce energy loss.

Key Components / Subsystems

- **Chamber / Housing**: Physical structure, insulation, materials (wood, metal, plastic, etc.) (Bharosh et al., 2021).
- **Heating element**: Bulbs, resistive heaters, etc (Bharosh et al., 2021).
- **Humidity control**: Water trays, steam or ultrasonic humidifiers; sometimes evaporative systems (Kifilideen et al., 2018).
- **Egg turning mechanism**: Motorized trays; automatic flipping at set intervals.
- **Sensors**: Temperature sensors (e.g., thermistors, DHT11), humidity sensors, sometimes CO_2, O_2 sensors (Kifilideen et al., 2018).
- **Controllers / Electronics**: Microcontrollers (Arduino, etc.), fuzzy logic controllers, PID controllers (Kifilideen et al., 2018).
- **User interface / Monitoring**: Display screens, remote monitoring (Wi-Fi / IOT), alarms if environment goes out of range (Kifilideen et al., 2018).
- **Power & Safety**: Power supply, backup power (where needed), safety mechanisms for overheating, door locks, etc (Kifilideen et al., 2018).

Performance Evaluation & Metrics

Key metrics for success

Hatchability rate of fertilized eggs that successfully hatch. Many studies show between ~70-95% (Alawad et al., 2021). Embryo mortality early compared to late mortality during incubation period (Ariffin et al., 2025). Uniform Temperature, humidity variation within the chamber, Energy consumption and Power required to maintain environment (heating, ventilation). Ease of use maintenance cost: Cost of production, reliability, labor requirements (Ghareeb et al., 2023).

Experimental Procedure

Product Planning (Design and Development)

The first step was to seek the market opportunities and to select a proper design of Incubator that has almost all the features that the customer need. After the market search and informal interactions with different groups and users, the team decided to go for the Automatic Incubator for domestic and small poultry forms use first. The market was thoroughly and carefully observed to what key features of the existing products that have to be considered in the designing. Similarly, the existing products are examined to identify the new technologies (if any) that can be incorporated in our product. Different complaints and problems associated with the existing products were also documented, later to be considered in the product development. This market analysis was carried out throughout our product development process. In addition to that the manufacturing facilities of our machine shop and possible constraints associated with it are also taken in consideration.

The financial budget and time frame of the project were one of the key components in developing our product prototype. With the continuous advanced research approach and development activities finally, we were able to establish the Mission Statement of our project, which enables and guide us to complete the rest of the product development phases. The whole process was analyzed repeatedly and refined time to time before deciding to launch our Mission Statement. We selected the project of Incubator because it was asked by one of the small poultry farm owners. He wanted to have a machine which can automatically control the different processes, that is portable, easy to use, easily programed and have safety measures.

Proper and effective planning plays an important and key role in the whole product development process. The strategy followed by our team in our product development process is briefly discussed as under:

The whole development process was decomposed functionally into sub groups; each phase of the planning was thoroughly and repeatedly analyzed and examined for further improvements and refinements. The data for the product features and functions have been collected through the market survey individually by each member of the team as well as thorough the external group search, similarly by brainstorming different ideas were generated and took into consideration while listing the customer needs. One of the key components of our planning was the thorough assessment of the collected data to create a good machine that can satisfy the customer needs. All the findings are then integrated collectively and applied to the product development. One of the important strategies of the planning phase was the assigning of group and individual tasks.

Concept Development (Marketing and Business Integration)

Identifying the Customer Requirements

key features of the mission statement and other related parameters in consideration, informal discussion with the friends and users a survey form was designed and distributed among different individuals so as to

collect the initial information and key desires of the customers. In addition to that, individual and focused group interviews were conduct.

As a result, the researcher came up with different needs that the customers want to be in the incubator. The customer's statements are thoroughly interpreted and converted to proper statements in terms of customer needs. The information gathering process is briefly discussed below:

The product planning phase and definition of the mission statement gave us certain direction to proceed further. Next was to identify the needs of the customers i.e. what the customer want to be in the incubator. The information from the customers were collected through the use of different available techniques which includes individual interviews with different users and customers, in addition to that focused group interviews were also carried out by the team members, similarly most of the information was also collected by observing different types of incubators available in market. In addition to that, written surveys were also carried out by the team members in order to get as many information as we could.

The information through interviews and surveys were collected from all categories of the customers who uses the incubator, such as, from the homeowners who use the machine occasionally to the people who frequently use them in heavy-duty environment such as farms and care houses. All the information was documented through the use of notes taking technique.

The data collected from the customers was in the raw form, which was interpreted carefully by the team members and converted to proper statements in terms of customer needs. Those statements are then organized in proper hierarchical list, showing categories of the primary and secondary needs. The key desires of the customers, which we considered to be in our product, are briefly discussed as follows:

The customers wanted the incubator to be cleaned with ease and safety, secondly they want the machine to be easily programmable which can run for the average time needed for egg to hatch. The machine should be able to rotate the egg all by itself. It should be able to control the temperature and should be able to turn off after the specific time, similarly some of the customers wanted to have an incubator that can be used for different number of eggs.

Primary and Secondary Customer Needs

- **Number of eggs the Incubator can accommodate.**
  The Incubator can be used for different number of eggs by changing the tray.
  Size of the Incubator
- **The Incubator prevents over heating i.e. controlled temperature**
  The feeder eliminates over heating i.e. controlled temperature
- **The Incubator automatically rotate the eggs**
  The incubator keeps rotating the eggs with the frequency set by the owner.
- **The Incubator is easy to operate**
  The Incubator has easy setup
  Easy to operate and clean
  Easy to refill
- **Different egg trays for different number of eggs**
  The egg holding trays can be made of different sizes to accommodate different number of eggs using same machine.
- **Sturdy and durable construction**
  Construction Material
  The feeder is portable
  Can use at outdoor
- **Can be used for different type of eggs**

By setting the different constrains the same machine can be used for eggs hatching of different birds.

- **Safety Features**

Safety to animal/children

Establishing the Relative Importance of Needs

After establishing the hierarchical list next was to establish the relative importance of each need. The available techniques for establishing the importance of the needs were used to pursue further i.e., a survey form was designed and distributed among different users from which the team came up with certain relative importance numbers of the features. Secondly the team members themselves had formal interactions with different customers in the market and came up with certain data. Finally, the findings of both the survey and team members were compared, analyzed and with the consensus of the team members, the relative importance number of each need was established.

Table 2: Relative Importance of Each Need

No.		Needs	Importance
1	Incubator	Easy to clean	3
2	Incubator	Easy to refill	2
3	Incubator	Can accommodate different number of eggs	5
4	Incubator	Make sure eggs rotate inside	5
5	Incubator	Light weight	5
6	Incubator	Can use at outdoor	4
7	Incubator	Stable	5
8	Incubator	Durable	5
9	Incubator	Safety to animal/children	5
10	Incubator	Easily Configurable	3
11	Incubator	Can run for specified days without owner's attention	1
12	Incubator	Protect the machine from over heat	5
13	Incubator	Can be used for eggs of different birds	4
14	Incubator	Save the electricity cos	2
15	Incubator	Low K value of Incubator body	5

The Unit Metrics

The working assumption of precise and measurable specifications is another key component of setting the initial and target specifications of the product. Hence, before proceeding to establish the specifications of the product, first the customer needs were translated in terms of proper units. Each and every need was considered and proper units have been assigned to them so that the measurable characteristic of the product clearly reflect the degree to which the product will satisfy the needs. We tried to translate the needs in practical and quantifiable units, e.g., in the below table, Timer setting has been assigned the unit "cycles/hour" clearly reflect at the number of times the timer can be set to rotate the egg in an hour.

Competitive Benchmarking

Establishing certain specific specifications for the product is one of the key design parameter in developing the product which needs great care and analysis, as the function, performance and outlook of the products can be greatly affected by establishing improper specifications.

In order to come up with proper specifications for our product, the team members carefully and thoroughly inspected the existing incubators in the market both physically and by referring to their manuals. Internet surfing played an important role in collecting the data regarding the specifications of the different incubators available in the markets and greatly help us in establishing the initial benchmarking for our product.

Table 3: List of Matrices Showing our competitive benchmarking of each need with the existing manufacturers

No.		Needs	Our product	Competitor 1	Competitor 1
1	Incubator	Easy to clean	3	2	3
2	Incubator	Easy to refill	2	4	5
3	Incubator	Can accommodate different number of eggs	5	1	2
4	Incubator	Make sure eggs rotate inside	5	0	0
5	Incubator	Light weight	5	4	5
6	Incubator	Can use at outdoor	4	2	4
7	Incubator	Stable	5	5	5
8	Incubator	Durable	5	5	5
9	Incubator	Safety to animal/children	5	5	5
10	Incubator	Easily Configurable	3	0	0
12	Incubator	Protect the machine from over heat	5	0	0
13	Incubator	Can be used for eggs of different birds	4	4	5
14	Incubator	Save the electricity cost	2	0	0
15	Incubator	Low K value of Incubator body	5	3	4

Key Features

Based on the analysis, the key features that we included in our product development process are the as under:

- The different number of eggs the incubator can have at a time.
- Most of the customers wanted the pet feeder to be able to control the rotation of egg.
- To control the number of cycles per hour for the rotation and for the time control signals for switching on and off of different devices we needed the “Timer Setting.”
- Another key feature was the control of temperature inside the incubator most of the customer wanted this system to be simple and precise.
- Similarly, the switching off of the whole incubator after the specified time (time needed for hatching of egg) was also one of the key features which was included in our design.
- In addition to that some customers wished to have use the incubator for different types of egg for which we have to make the temperature setting external or owner control.
- Other key features which we took in to considerations were the material for the body and different parts of incubator.

Preliminary and Target Specifications

After establishing the competitive benchmarking, next was to establish the initial and final target specifications for the product. The team members after detail discussions and analysis of the collected data we were able to set the ideal and marginal values for the needs.

These preliminary specifications were then again analyzed and compared with the standards and other manufacturer's specifications and finally reasonable target specifications were established. The final values are carefully and thoughtfully established according to the standards, we tried our best to meet the required standards and most of the values are near or better than the marginal values.

For developing the best concept for our product, the existing products already available in the market were studied, different pictures and videos of the incubator available were viewed available online. Similarly, different manuals were thoroughly studied and their designs were analyzed, latest developments and new features that could be included were searched through net surfing and magazines. Our goal in the concept generation was to come up with a best concept, which will include the important features. Some of the important needs which we took in consideration in the concept generation process were the number of eggs the incubator can accommodate at a time, similarly most of the customers wanted the full automation of the incubator, another was the type and location of the controller i.e. the controller of the incubator should be easy to operate and also should be located at safe place to ensure safety from the animal and small children. Accordingly, some of the concepts were generated by considering the needs/features that are more important to the customers.

A standard methodology was adopted during the concept generation process i.e. First of the entire product was decomposed into subgroups taking into account all the above needs according to their relative functions, features and customer needs. Then we look for the possible combinations of these features in which they can be assembled, the combinations were made by classification trees and combination table technique. Again, in this phase internal search along with external search was carried out to gather information on all the requirements.

After thorough analysis of the possible feature combinations, five different concepts were generated that could be implemented to the development of the product.

The Concept Generation Methodology

Power Source

The first and important feature which was considered in the concept generation process was the energy or power source of the product. There were many options available which could have been used for its controls and driving mechanism. To use the power source that doesn't affect the cost of the incubator and also kind of easily available everywhere we used AC source.

The Controller

Two factors were considered in concept generation for the controller i.e. the type or Mechanism of the controller and second was position or location of the controller that where it should be located so as to ensure the safety concerns.

The possible position of the controller could be at the Top, Side and Bottom, similarly the mechanism of the controller could be controlled through the use of logic circuit or through the use of microcontroller. Microcontrollers could be then of programmable type or embedded system. After discussions and keeping

the goals of our mission statement we decided the controller to be of the programmable type which should be located at the bottom back side of the feeder, so that it could not be visible to the small children or pets.

The Storage

Another important feature of the incubator which was considered in the concept generation was the number of eggs that the incubator can have at a time which is somewhat directly related to the aesthetics. After comparing all the possible combinations, the team selected to design a rectangular tray that can be taken out of the incubator's body, we made this decision because the egg can be placed with care and 2nd it can be cleaned easily, and third it could be easily manufactured with the existing facilities of the machine shop.

Time Setting

Two types of timers could be used for the purpose i.e., "Mechanical" or "Digital". The digital timer could be then operated locally at its interface or through a remote control. Similarly, the display of the timer setting could be displayed by using a 7-segment display or through LCD.

The team selected a digital clock with an LCD as they are easily available and can easily be controlled through logics.

Safety Features

This is also one of the key features of our design considerations. In the concept generation the safety features were categorized in two categories depending upon shape and features of the product. Shape refers to the general structure, edges, corners and controllers of the incubator, there were many options which could be included in designing the incubator, among them we selected a square box which has a tray for holding the eggs and shafts which makes the oscillatory motion of the tray possible, which besides safety also impart aesthetic touch with in the feature.

Features which we took into account during the concept generation were the warning labels that could be pasted at particular locations such as near the electrical connections and controls etc. similarly the material of the incubator should be Nontoxic, and it should be air tight which helps in keeping the inside temperature in close limit.

Results

Final Design (Mechanical and Thermal Design)

After thorough analysis of the combinations, alternatives and taking all the above concepts into considerations we selected the following incubator. The 3D model of the selected concept was generated using solid works.

The main feature of the final selected design is that it can be modified so as to be used for different number of eggs. The mechanism is simple and very easy to understand which can be easily operated by any customer. In addition to that aesthetic look is also very excellent.

Below is the final 3D model of the final selected concept.

Final 3D CAD Sketches of the Developed Concepts

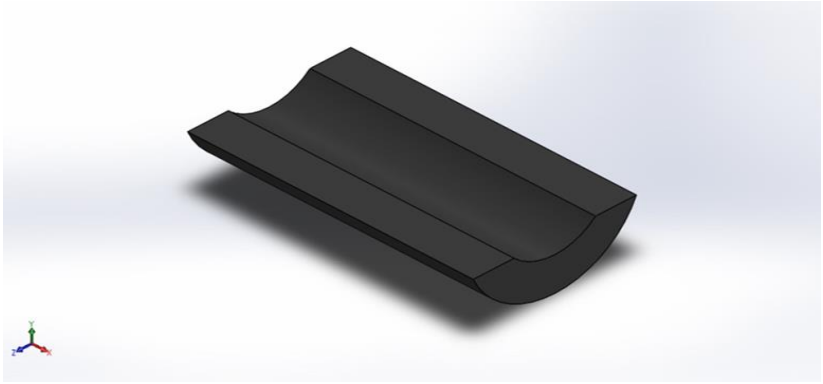

Figure 1: The Foam Used for Egg Rotation

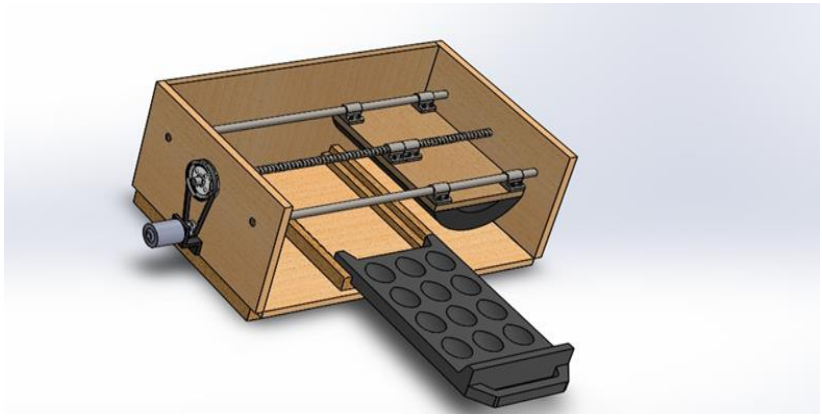

Figure 2: Tray Used for Holding Eggs

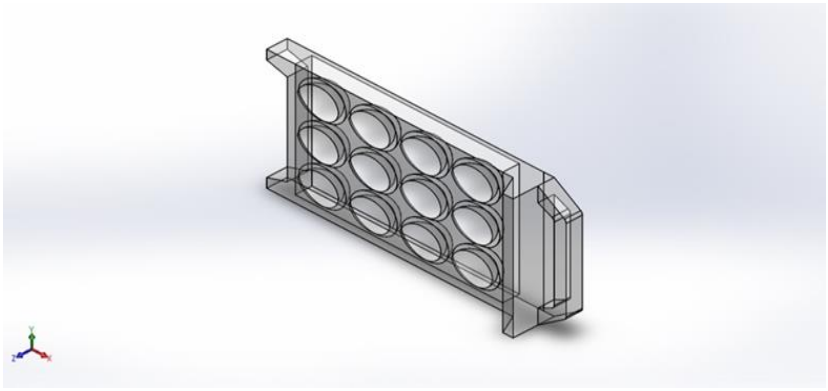

Figure 3: Tray Used for Holding Eggs

Thermal Analysis Results of Different Parts

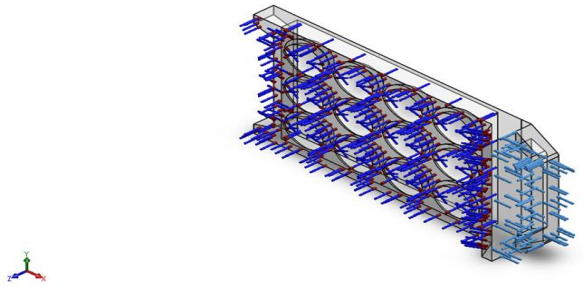

Figure 4: Thermal Analysis of Inner Parts

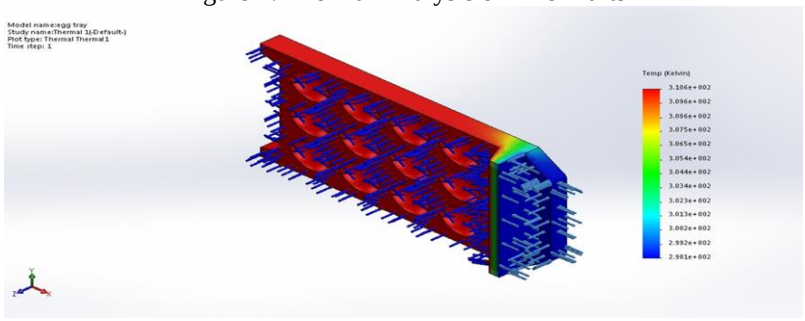

Figure 5: Thermal Analysis of Inner Parts

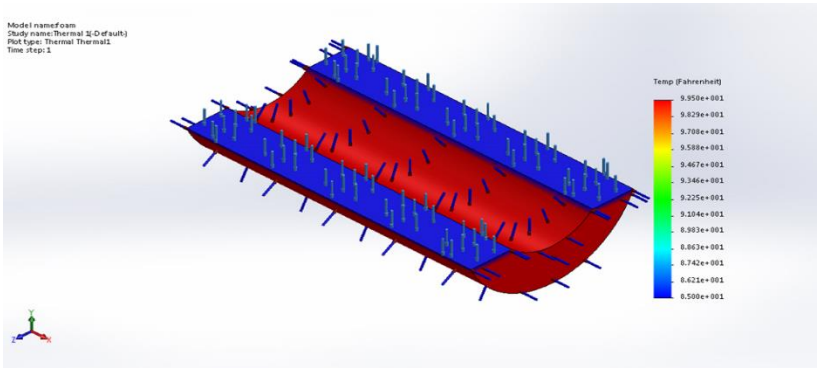

Figure 6: FEA Therma lAnalysis

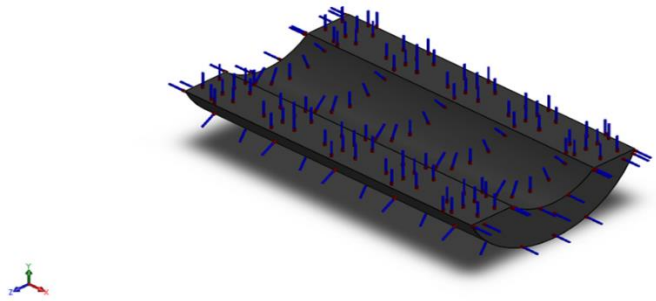

Figure 7: Boundary Conditions for Applied Loading Conditions

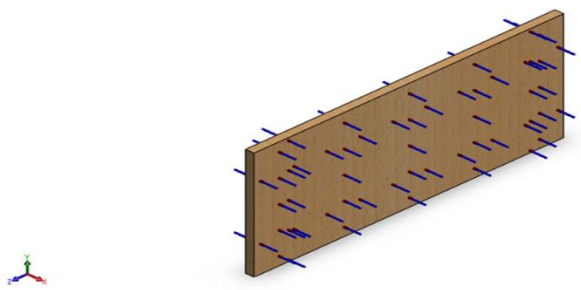

Figure 8: Thermal Analysis for Boundary Conditions, Convection or Thermal Load

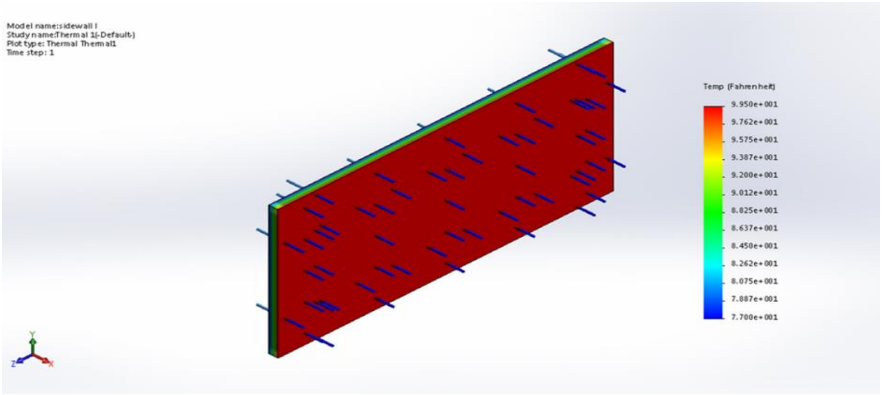

Figure 9: Thermal Analysis for Total Heat Flux, Convection Across Side Wall

Stress Analysis Results of Different Parts

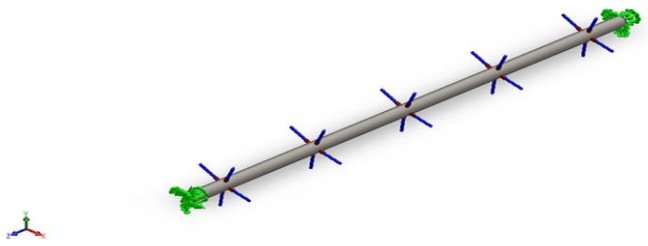

Figure 10: Rotary Tiller Blade Assembly

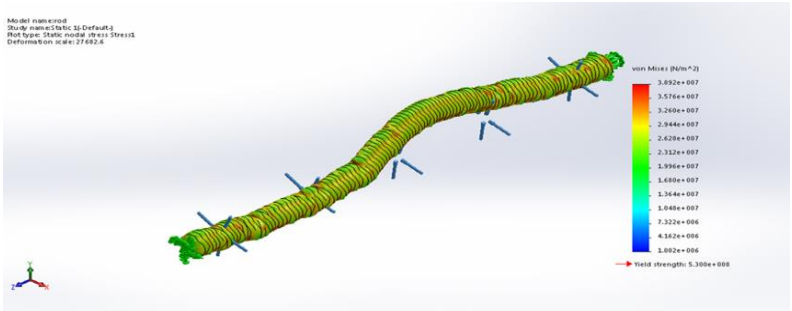

Figure 11: Stress Distribution Analysis

Economic and Marketing Analysis

Cost Breakdown

- Microcontroller (ESP32): $2
- Sensors (SHT31, DS18B20): $5
- Motor/driver: $8
- Heater pad & SSR: $13
- Fan & power supply: $18
- Cabinet & insulation: $10
- Display & UI components: $5
- Misc (wiring, fasteners): $4
- Labor/overheads (prototype): $15 **Total prototype cost (est.)**: $74

Market Impact and Strategies

Market Overview

- Primary markets: small-scale poultry farmers, colleges and universities, backyard hobbyists, and research labs.
- Market drivers: local hatchery shortages, rising demand for poultry, education/DIY interest and desire for automation.

Segmentation & Targeting

- Segment 1: Small commercial farmers (prioritize reliability and capacity)
- Segment 2: Hobbyists/backyard (lower cost, plug-and-play)
- Segment 3: Educational institutions (robust safety features, classroom kits

Value Proposition

Reliable hatches with precision control automate your incubation and increase hatch rates with minimal effort.

Competitive Analysis

- We compare the domestic and imported incubators with difference in some features like Wi-Fi, data processing and other automatic control features.
- By comparing with domestic and imported incubators we found it that this automatic incubator has easy maintenance, modular upgrades and remote monitoring.

SWOT Analysis

- The main strengths of this incubator have customized low cost, remote monitoring values and automatic control abilities.
- The main weaknesses weakness of this incubator is its commercial brands and initial brand recognition as compared to its prototype durability.
- The main big opportunities of this new designed incubator are its educational partnerships with researchers for industrial use, partnerships with local markets investors and franchising repairs
- The big threats are there will be a seasonal demand, import low-cost domestic incubators.
-

Marketing Impact Assessment

Economic Impact

The designed incubator can play very important role in the economic section of the market. This designed incubator can reduce the labor costs, reduce the losses occur due to human error or due to some atmospheric conditions. Similarly, it is very helpful for supply chain like in the poultry meat and egg markets the chick supply helps food and storage processing. The main big economic impact is that it will provide opportunity for manufacturers and businessman to produce automatic incubator locally that will be easily available for customers.

Social impact and Food Security

The designed automatic incubator can help to improve food storage and eggs hatching rate for better productivity and availability in the market because in large amount countries in the world the poultry is a big source of protein. Similarly, it will also allow the farmers and the businessman to use the automatic incubator locally rather than import chicks from outside countries.

Environmental Impact

As the incubators required heating for hatching which consumes large amount of electricity and also increase carbon dioxide in the environment. Therefore, the designed incubator is an energy efficient design that provide large amount of hatching rate with small electricity consumption. Similarly, the inner surface of the design incubator is properly insulated therefore, there will be a renewable energy option also available in this incubator, and also has the small rate of waste eggs as compared to domestic incubator.

Challenges, Risks, and Barriers

While with increasing the hatching rate, energy consumption rate and other better performance as compared to domestic incubator, there will also be some challenges and risks in the designed automatic incubator. The most common challenges and risks are the price of automatic incubator is more than that of domestic incubator, the sensors that are using in automatic incubator may sometimes fail and need to be repair, the new users need to understand the basic functions that how it works calibrate.

Conclusion

In this research study the design and analysis of an automatic incubator were discussed. The incubator was designed and then analyzed their inner surfaces by using FEA analysis, thermal analysis, stress analysis which show that this designed automatic incubator can maintain high temperature, high bending stress and high loading stress. The designed incubators keep an important role for increasing the productivity of poultry, decrease losses, important role in food security in the region of those areas where the demand of meat and eggs are mostly high. The designed incubator that has relatively high cost as compared to domestic incubator but provide high hatching rate, improve efficiency from 85 to 95 percent, automatically control the heating and loading process.

Encouraging local manufacturing and promoting modular, scalable designs can further reduce production costs and support wider adoption among small and medium scale poultry farmers. In addition, support from governments and NGOs through subsidies, training programs, and accessible credit schemes can play a crucial role in helping farmers acquire and effectively use improved incubation technologies. Continued research aimed at optimizing control algorithms, improving energy efficiency, and developing species-specific incubation profiles will further enhance the performance and adaptability of automatic incubators, supporting more sustainable and profitable poultry farming systems.

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