Revolutionizing Incubation: Harnessing the Power of Embedded Systems for a Smarter Future

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***Abstract*—Nowadays, conventional methods employed by hatchery operators lack precision and real-time monitoring capabilities, posing challenges for egg farmers, especially those residing in rural areas. The traditional practice of allowing chickens to incubate eggs is slow, labor-intensive, and often unsustainable, particularly with low chicken populations. Daily monitoring of individual eggs is necessary to ensure optimal growth conditions. However, limited internet access in rural areas and the necessity for power-efficient solutions make it difficult to find suitable applications to assist egg farmers in their endeavors. This necessitates the introduction of a new type of low-power and efficient incubator, incorporating sensors and microprocessors such as the ESP32, which have become increasingly affordable. Engineers have successfully developed an embedded system that assists egg farmers, significantly enhancing the efficiency and ease of the hatchery process at a cost that is highly accessible.**

***Index Terms*—Embedded system, esp32,engineers,incubate eggs,incorporating sensors,real-time monitoring**

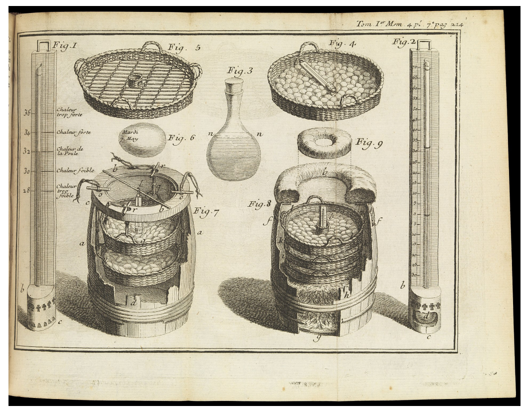

Fig. 1. Egg incubator in the 17th century.

I. Introduction

Embedded systems are essential components that control various modern devices, providing dedicated computer functionality within broader mechanical or electrical systems. This paper focuses on the application of embedded systems with real-time sensor-based monitoring in the field of egg hatching. Manual monitoring and provision of ideal environmental conditions for successful incubation pose significant challenges for small egg farmers, limiting their profitability compared to larger industrial operations. However, by integrating affordable sensor solutions and advanced data analysis techniques, embedded systems offer a transformative approach to improve efficiency and profitability. This study explores the design and development of an embedded system utilizing sensors for real-time egg monitoring, aiming to enhance the egg hatching process and empower small-scale farmers to achieve higher hatch rates and compete effectively in the industry.

II. Related Work

A. Previous work

The concept of artificial incubation can be tracked back to ancient times, where methods such as placing eggs in warn sand or using natural heat sources were employed in order to for the hatching process to be successful. Although, these methods lacked precise control and were most often unreliable. Going in the early 17th century, the development of thermometers and an advanced understanding of temperature's role in embryonic development led the way to the creation of rudimentary egg incubators making using the days knowledge. Moreover, these early designs relied on manual adjustments and closely monitoring temperature fluctuations. Moving to the 19th century the emergence of mechanical incubators powered by steam, hot water, and oil kicked in. These egg incubators featured mechanical mechanisms for egg turning and improved insulation to maintain stability and humidity levels to preserve the eggs. Later, with the advent of electricity in the late 19th century, electrically heated incubators were introduced. To be more exact, electric incubators provided much more precise temperature control flow and eliminated the need for manual control over the device and for fuel management compared to old ones powered by steam. As a result, this development improved at a great extent hatching rates and made egg incubation more accessible to a wider variety of people-audience. Furthermore, in the late 20th century, the incorporation of microprocessors and electronic controls brought further advancements to the existing devices. Analytically, the microprocessors allowed for further accurate and sophisticated temperature, humidity and ventilation control flow minimizing human error and improving furthermore the incubation process. In recent years, the advancement of embedded systems and automation technologies has made the egg machines into smart devices. Also, the deployment of Internet of Things has facilitated the development of connected egg incubators, enabling the breeders to remotely monitor and control the incubation process, receiving real-time notifications, and having access to data using smartphone devices or web interfaces.

B. Motivation

The development of an embedded system for egg incubation arises from the need to address the challenges faced by hatchery operators and egg farmers. The following points outline the fundamental motivations driving the creation of this innovative technology:

- Enhancing the efficiency and success rate of egg incubation processes.
- The objective is to provide real-time monitoring and precise control of environmental factors, resulting in improved hatch rates and overall productivity.
- Providing immediate and accurate data on critical parameters such as temperature, humidity, and egg turning, ensuring optimal conditions for egg development.
- Reducing reliance on conventional manual monitoring methods and mitigating the risks associated with human error.
- Increasing the accessibility and affordability of advanced incubation technologies for small-scale egg farmers, fostering sustainability and economic growth.
- Improving the overall quality of hatchery operations, contributing to the development of a more efficient and sustainable poultry industry.

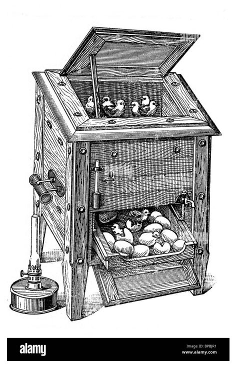

Fig. 2. Egg incubator in the 19th century.

III. Exploring the Technological Advancements of Smart Egg Machines: A Comprehensive Overview

A. Quantitative Assessment of Hen Performance versus Smart Egg Incubators: A Comparative Analysis of Reproductive Efficiency

Smart egg Incubators, nowadays, have proven to be a technology that has untapped great potential. More analytically, farmers are permitted to breed chicks from eggs without the consent of the mother chicken, which is also one of the options.The primary distinction between natural and artificial hatching is that biological parents provide warmth and on the contrary from the new technological side we make use of warm air. Also, the most important and crucial aspects are been shown in fig3 below.

No.	Aspect	Natural (hens)	Smart Egg Incubator System
1.	Technique	• Not always broody when required • Not always cooperative	• Always available
2.	Labour costs	• Extra feeding required • A minimum of sanitation required • Water • Shelter • Protection	• Heat source • Checking and regulating the temperature • Building the incubator • Turning the eggs artificially • Filling the water container
3.	Construction costs	Limited • Nesting boxes	• Local material • Esp 32 • Fan • Lamp
4.	Running costs	Limited • Straw sawdust	• AC supply: electrical bill
5.	Performance and results	• Natural hatching conditions guaranteed (temperature, relative humidity, ventilation) • Hatching qualities: local breed	• Almost optimal Conditions • Improved breeds may permanently produce eggs over a long period
6.	Risks	• Few risks	• Loss of all or some of the eggs

Fig. 3. Divergent Dimensions of Natural (Hens) and Technological (Smart Egg Incubators) Approaches: A Multifaceted Exploration.

B. Investigating the Incubation Period

1) Natural incubation: It occurs when a hen starts to sit on the fertilized eggs until the appearance of the chicks. During natural incubation, the hen provides the necessary temperature for the proper development of the offspring. This incubation process typically lasts for 21 days.

During incubation, it is essential to maintain all the necessary environmental factors (appropriate temperature and humidity) as well as hygiene conditions to achieve the desired results. In fig4 we can how specific are the conditions for each type of egg.

Species	Incubation Period (days)	Temp (F)	Humidity (F)	Do not turn after	Humidity Last 3 days	Open vent more
Chicken	21	100	85-87	18^{th} day	90	18^{th} day
Turkey	28	99	84-86	25^{th} day	90	25^{th} day
Duck	28	100	85-86	25^{th} day	90	25^{th} day
Muscovy Duck	35-37	100	85-86	31^{st} day	90	30^{th} day
Goose	28-34	99	86-88	25^{th} day	90	25^{th} day
Guinea Fowl	28	100	85-87	25^{th} day	90	24^{th} day
Pheasant	23-28	100	86-88	21^{st} day	92	20^{th} day
Peafowl	28-30	99	84-86	25^{th} day	90	25^{th} day
Bobwhite Quail	23-24	100	84-87	20^{th} day	90	20^{th} day

Fig. 4. Incubator Conditions for Diverse Egg Types: A Comparative Analysis.

2) Artificial incubation: Artificial incubation is achieved using incubation machines (incubators). Successful artificial incubation can be achieved by employing machines with proper temperature control, humidity control, and ventilation. A very important aspect of the incubation process is maintaining the correct temperature in the incubator and ensure that it is stable throughout the whole incubation period. Additionally, since eggs lose moisture during incubation, incubators provide the appropriate environment by increasing humidity whenever required.

During incubation, it is also crucial for the eggs to breathe and for there to be clean air in their environment to provide the necessary oxygen. Therefore, incubation machines have suitable ventilation mechanisms.

Incubation period:	Temperature	Humidity
1st - 7th day	37,9	50 Rel. Hum
8th – 14th day	37,8	55 Rel. Hum
15th – 17th day	37,5	65 Rel. Hum
18th – 21st day	37,2	70 Rel. Hum

Fig. 5. The proposed temperatures in the article's smart embedded system.

The turning of the eggs occurs every 4 hours, besides the final 3 days of the incubation period. While incubation machines serve to create ideal conditions that allow fertilized eggs to continue their embryonic development, which has already begun before oviparity, until the hatching of the offspring, something equally important as making sure the environmental conditions for the egg incubation are optimal is making sure the eggs are all fertile. One way to achieve this is by using an ovoscope, with which we can observe the interior of the egg. Lastly, it is important to remember that in order to achieve optimal success rate, equal attention must be given throughout the entire cycle, from the egg formation in the mother to the birth of the offspring.

Fig. 6. Ovoscope example.

Fig. 7. Egg Development through 21 days.

IV. Proposed Embedded System Architecture and Design

A. System Specifications

Fig 8 below shows the exact specifications of the designed embedded system that has been made by our team. It is consist of eggs capacity,what type of eggs it can hatch, sizes, weight, power,voltage and frequency.

No.	Technical Specifications	
1	Egg Capacity	12 Eggs
2	Can Hatch	12 chicken eggs, 12 duck eggs, 6 turkey eggs, 24 quail eggs
3	Sizes(L*W*H)(cm)	42cm x 42cm x 46cm
4	Weights(kg)	1 kg
5	Power(W)	~75 W
6	Voltage(V)	240 V
7	Frequency(Hz)	50 Hz

Fig. 8. Technical specifications.

The incubator consists of the main body, made out of expanded polystyrene housing:

- 1 60-watt halogen bulb2
- 2 fans measuring 5 * 5 cm
- 1 lamp socket for the bulb
- 1 DHT22 pressure and temperature sensor
- 1 12-slot egg tray
- 1 LCD2004+I2C display

And a wooden box on top of it housing:

- 1 ESP32 (Wemos D1 UNO R3 D1 R32 WIFI)
- 2 fans 5 * 5 cm , 12volts
- 1 relay (4 channel module with optocoupler).
- 1 PSU 220volts AC to 36 volts DC - 180watts
- 1 transformer 220 volts AC to 12 volts AC
- 2 DC-DC Step Down Converter Module (LM2596S)
- 1 ON/OFF switch.

When the temperature is below the optimum level, the light will be turned on to generate heat. Once it rises to the optimum level the light turns off. Conversely, when the temperature is above the optimal temperature, the fan will turn on to lower the temperature, turning off once it reaches it. Incubation lasts as long as the development and growth of the egg. It is the process of fertilizing an egg (oviparity) until the hatching of the offspring. In other words, it refers to the period of embryonic development inside the egg. The incubations have been described above in this article.

B. Methodology

By referring to Figure 9 above, it shows the project development was divided into three main parts. There are mechanical design, electronic design and software design.

C. Mechanical design-Electronic design

The incubator, operates with a voltage of 220 volts AC, which is then converted to 36 volts DC through the power supply unit (PSU). Additionally, the transformer also converts the 220 volts AC it is powered by to 12 volts AC to operate the mechanism that rotates the eggs.

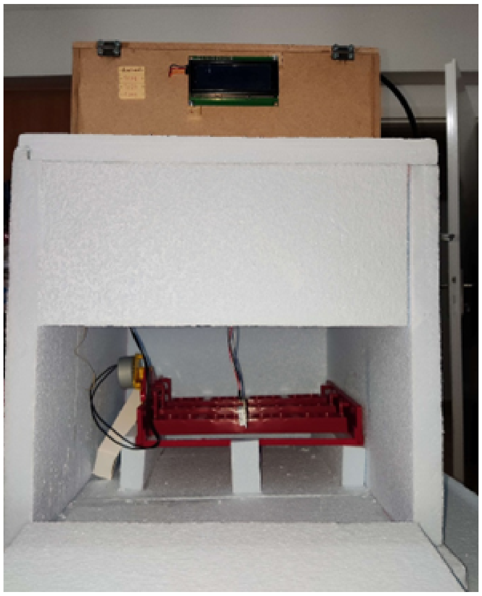

Fig. 9. System mechanical construction

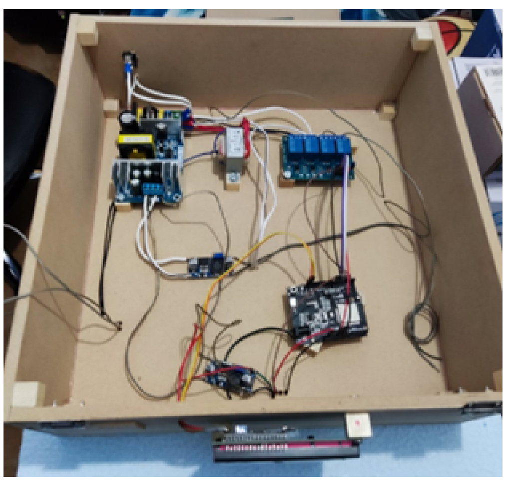

Fig. 10. System Electrical Design

Fig. 11. Power energy management

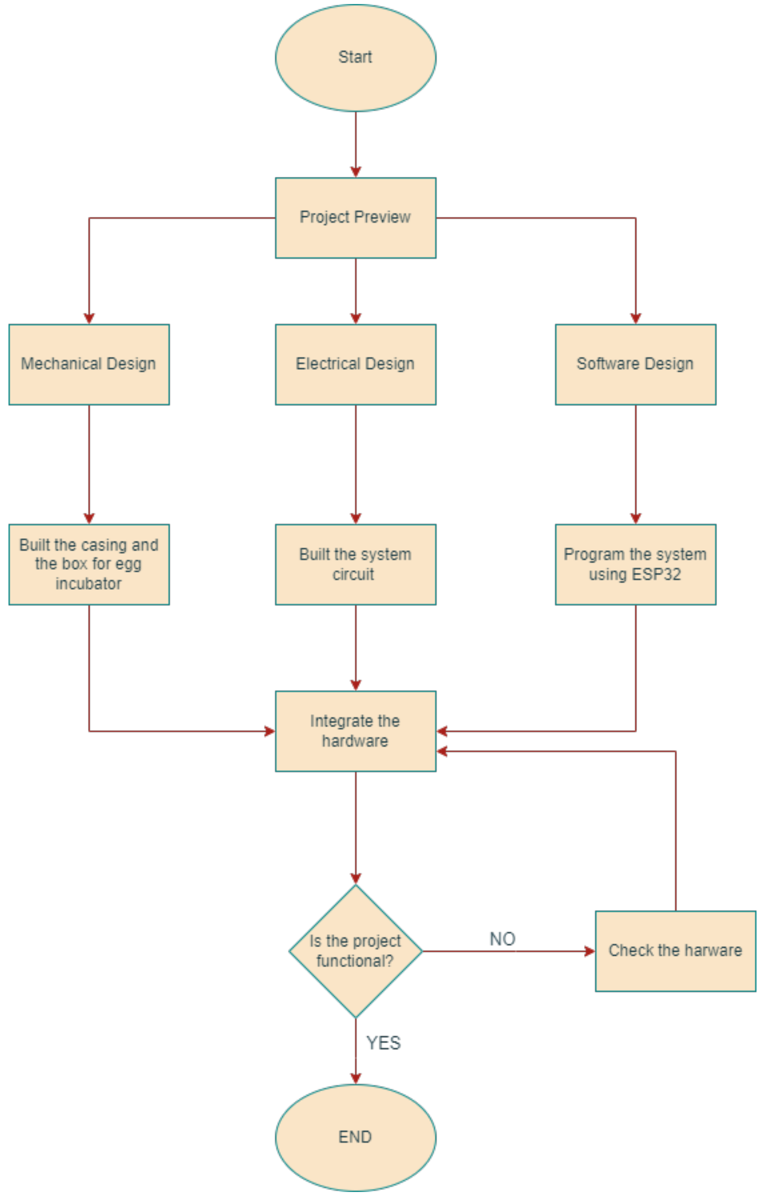

Fig. 12. Methodology of the embedded system

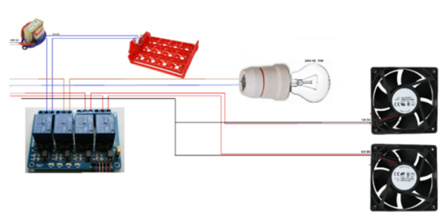

Fig. 13. Entire wiring of the incubator

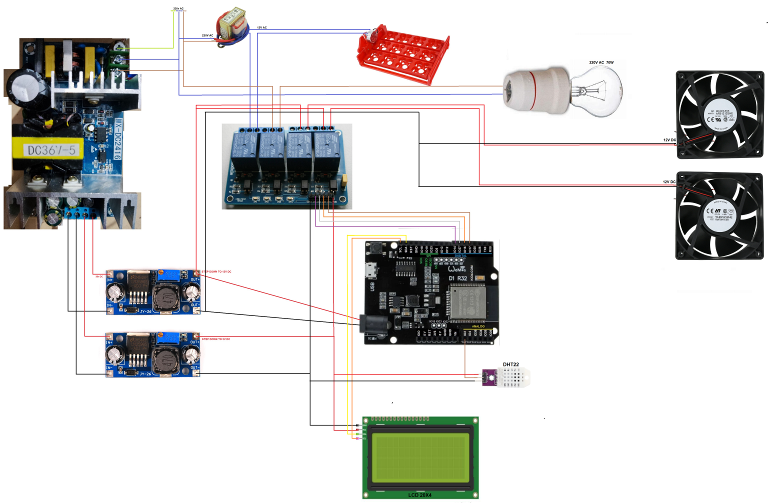

Fig. 14. System Design diagram

ITEMS	QUANTITY	PRICE	COST
PSU AC TO DC 36V-180 WATTS	1	15	15
Wemos D1 UNO R3 D1 R32 WIFI	1	4,5	4,5
STEPDOWN DC TO DC	2	1,15	2,3
HALOGEN LAMP 60 watts	1	2	2
NTOUI E27 / Power Switch	1	1	1
EGG BASE	1	16	16
LSD 2004+I2C	1	5,8	5,8
EXPLODED POLYSTYRENE	1	8,5	8,5
5X5CM AIRFAN	2	2,5	5
WOOD MDF+WOOD-GLUE	1	14	14
AC TO AC ΜΕΤΑΣΧΗΜΑΤΙΣΤΗΣ	1	4,5	4,5
HUMID+TEMP SENSOR	1	3,5	3,5
4CH RELAY MODULE	1	2,5	2,5
Total cost -->			**84,6**

Fig. 15. Cost table of the embedded system

The central control is done by the ESP32, which communicates with:

- The relay module with 4 digital outputs: ch1 = IO14, ch2 = IO27, ch3 = IO16, and ch4 = IO17.
- The DHT22 sensor with 1 analog input: out = IO2.
- And with the LCD 2004 module through the I2C protocol.

In the figure 13, you can see the entire wiring of the incubator, where we can distinguish how the 4 channels of the relay module activate various mechanisms, specifically:

Ch1: activates the base that moves the eggs. Ch2: activates the lamp. Ch3: activates fan 1. Ch4: activates fan 2.

D. System cost

In figure 15, we can see the cost table of the embedded system.

E. SWAT analysis

Strengths:

- **Automation**: A smart egg incubator offers automated features such as around the clock temperature control and humidity monitoring, automatic egg turning and ensuring optimal environmental conditions for egg incubation.
- **Connectivity**: It can display results online, allowing users to monitor the status of the incubator remotely, enabling users to stay updated on the incubation progress.
- **Data tracking**: Smart incubators can collect and analyze data on temperature, humidity, and other crucial factors, providing users with valuable insights and enabling them to make informed decisions during the incubation process.
- **User-friendly interface**: Smart incubators typically have user-friendly interfaces, making it easy for both beginners and experienced users to operate and navigate the device effectively.

Weaknesses:

- **Cost**: Smart egg incubators can be more expensive compared to traditional incubators due to the additional technology and connectivity features. This higher cost may be a deterrent for some potential buyers especially farmers living in rural areas who might not be as tech-savvy.
- **Technical issues**: Technical malfunctions or software glitches in smart incubators can disrupt the incubation process or require technical expertise for troubleshooting.
- **Dependency on connectivity**: If the connection is lost or incompatible, users may face difficulties accessing the incubator remotely.

Opportunities:

- **Demand**: There is a growing interest in smart home devices and automation, creating an opportunity for smart egg incubators to cater to a niche market of tech-savvy and convenience-seeking poultry enthusiasts.
- **Education and research**: Smart incubators can be used as educational tools in schools and universities, allowing students to learn about the incubation process and monitor the development of embryos in real-time.

Threats:

- **Competition**: The market for egg incubators is competitive, with both traditional and smart incubators available. Competitors may offer similar features or alternative solutions at lower prices, making it challenging for a smart incubator to stand out.
- **User acceptance**: Some users may prefer the traditional hands-on approach to egg incubation and may be reluctant to adopt a technology-driven solution. Convincing them of the benefits and reliability of a smart incubator may pose a challenge.

V. Discussion

Several factors have to be considered for the successful process of incubation and hatch of the system. There are

TEMPERATURE

TIME	0:00:00	0:00:30	00:01:05	0:01:20	0:02:00	0:02:15	00:03:15	00:03:30	0:04:55	0:05:55
TEMPERATURE TZONE1(1-7DAYS)	28	38,2	37,5	38,2	37,5	38,2	37,5	38,2	37,5	38,2
TIME	0:00:00	0:00:11	0:01:15	0:01:20	0:02:05	0:02:15	0:03:15	0:03:22	0:04:37	0:05:48
TEMPERATURE TZONE2(8-14DAYS)	37,5	38,5	37,5	38,5	37,5	38,5	37,5	38,5	37,5	38,5
TIME	0:00:00	0:00:30	0:01:05	0:01:20	0:02:00	0:02:15	0:03:15	0:03:30	0:04:55	0:05:55
TEMPERATURE TZONE3(15-17DAYS)	37	37,9	37	37,9	37	37,9	37	37,9	37	37,9
TIME	0:00:00	0:00:10	0:01:05	0:01:12	0:02:18	0:02:23	0:03:15	0:03:30	0:04:55	0:05:51
TEMPERATURE TZONE3(18-21DAYS)	36,6	37,2	36,6	37,2	36,6	37,2	36,6	37,2	36,6	37,2

RELATIVE HUMIDITY

TIME	0:00:00	0:00:10	0:05:05	0:05:20	0:10:00	0:10:15	0:16:15	00:16:26	0:21:55	0:22:04
REL. HUM. TZONE1(1-7DAYS)	55	51	55	51	55	51	55	51	55	51
TIME	0:00:00	0:00:10	0:05:07	0:05:21	0:10:02	0:10:15	0:15:55	0:16:04	0:21:45	0:21:55
REL. HUM. TZONE2(8-14DAYS)	60	56	60	56	60	56	60	56	60	56
TIME	0:00:00	0:00:08	0:05:11	0:05:20	0:11:00	12:11:12	0:16:09	0:16:15	00:21:10	00:21:16
REL. HUM. TZONE3(15-17DAYS)	70	66	70	66	70	66	70	66	70	66
TIME	0:00:00	0:00:09	0:05:06	0:05:23	0:10:11	0:10:19	0:16:15	0:16:21	00:21:13	00:21:93
REL. HUM. TZONE3(18-21DAYS)	75	71	75	71	75	71	75	71	75	71

Fig. 16. Temp and humidity tables

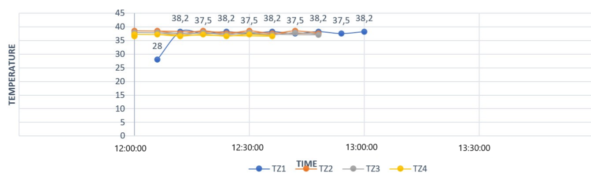

Fig. 17. Temperature graph

two major factors in artificial incubation: temperature and humidity.

We have programmed the embedded system to send real-time values to an app called Bing and in this way we can have live tracking of the internal environmental conditions of the incubator. As we have shown in the above diagrams,our design takes and sends very accurate data to frequently update the results. In the future, we could use opencv to automatically recognize the eggs' species using AI technology and we could also implement remote control function as well as one live updated server-site of our own.

In the fig 17, we can mark some temperature and humidity tables and also one temperature diagram during one hour of working.

Conclusion

In this paper the component designed is easy to maintain, affordable and portable. The incubator offers the ability for eggs of different poultry to hatch such as quail, turkeys, ducks etc. The incubator is recommended for household use, subsistent poultry farmers to increase the production of poultry products. Besides that, another recommendation is that solar energy be used as a backup power supply to enhance the efficiency and reliability of the system.

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