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# Design for a Low-Cost Fuzzy-Based Leopard Gecko (*Eublepharis Macularius*) Egg Incubator for Improved Hatchery Rate Conditions

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***Abstract***-- *In the incubation of Leopard Gecko eggs, fluctuations in temperature and humidity control can drastically affect the hatching success. Homemade incubators that rely on room temperature are prone to this dilemma. Despite their inexpensiveness, their operability is limited to specific values. In contrast, incubators available in the market perform well but are relatively expensive. This study focused on developing and testing a low-cost fuzzy-based design to improve the hatchery rate conditions of a Leopard Gecko egg incubator. The study employed a descriptive quantitative research design utilizing descriptive statistics to evaluate the incubator's responsiveness and accuracy. Paired sample t-test was employed to test the null hypothesis and determine the relationship between the incubator design and its performance. The study revealed that a fuzzy-based incubator could improve incubation conditions in comparison to a non-fuzzy-based incubator ($t_{temp}(1000) = 30.448$, $p < 0.01$ and $t_{humidity}(1000) = -159$, $p < 0.01$). In addition, it is cheaper compared to incubators available on the market. However, the correlation between performance and incubator design is low (r for temperature is 0.291 and r for humidity is 0.033). Thus, the researchers recommend engaging the prototype in actual incubation testing, using an incubator medium, to verify its efficiency in hatching Leopard Gecko eggs.*

***Keywords***— *Leopard gecko, fuzzy-based incubator, egg hatchery.*

## I. Introduction

### *1.1 Rationale*

The pet industry encompasses far more than just dogs and cats. While most research into the human-animal bond focuses on the special relationship that has evolved over thousands of years between people and dogs, today's pet owners do not limit their connection with animals to just dogs or cats. Some animals like fish, birds, and reptiles have also found their way into the hearts of other pet owners (Sukandar et al., 2020). In fact, in a survey by Statista.com, France ranked first in the European Union with a reptile population of approximately 1.09 million in 2020, followed by Spain with nearly 1.24 million. The leopard gecko (Eublepharis macularius) is one of today's most common and popular reptiles. As the number of reptile enthusiasts grows, so does the number of people interested in becoming breeders, including Leopard gecko breeders. Female Leopard Geckos store male sperm in their bodies and may lay eggs up to 5 times per period, with each period of female eggs laying up to 1 to 2 eggs (Lin, 1998). As a breeder, an incubator is a vital tool to obtain to hatch offspring after breeding successfully (Noel et al., 2012).

(Flores et al., 1994) mentioned in their study that the leopard gecko has temperature-dependent sex determination (TSD); females are produced at 26 degrees °C (100 percent), 30 degrees °C (70 percent), and 34 degrees °C (95 percent), while males at 32.5 degrees °C. (75 percent). Animals from male-biased incubation temperatures were more likely to be aggressive as adults than animals from female-biased incubation temperatures. Females from male-biased incubation temperatures were also less attractive than females from female-biased incubation temperatures. Females who were hormone-determined were both amusing and aggressive. It implies that incubation temperature is a factor that affects aggressiveness and attractiveness in developing leopard geckos.

Another study conducted by (Rhen & Crews, 1999) also states that a female-biased sex ratio (approximately one male to three females) is produced by an embryonic temperature of 30 °C, while a male-biased sex ratio (approximately one male to three females) is produced by a temperature of 32.5 °C (approximately three males to one female). Also, they coincide with the results of Flores's study, wherein it is shown that sexual differentiation of behaviour in the leopard gecko is influenced by gonadal sex and embryonic temperature. Nonetheless, it is unclear whether such effects are activated or organized because no systematic study of temperature and sex effects on reproductive and aggressive behaviour while controlling for circulating hormone levels has been conducted.

In research by (Jančúchová-Lásková et al., 2015), 15 female Leopard geckos laid eggs from the mating of one breeding male Iraqi eyelid gecko and 17 virgin female Leopard geckos. The hatchability of first-generation hybrids was 44% (70 eggs were incubated at a temperature of 28° C). This value is comparable to the Iraqi eyelid gecko (34% hatchability, 38 eggs incubated at 26 °C). However, it seems lower than the value of the leopard gecko (92% hatchability, 87 eggs were incubated at 28° C). Of the 31 first-generation adolescents, 25 women and three men survived for a year (90 percent). Survival rates were similar to those observed in the parent species (Leopard Gecko 84%, Iraqi eyelid gecko 85%, n = 80 and 13).

These first-generation hybrids were bred further to produce F2 generations. A pairing of three first-generation hybrid males and 13 first-generation hybrid virgin females was made, resulting in all first-generation hybrid females laying eggs. A total of 71 eggs were incubated (16 eggs at 26°C and 55 eggs at 29°C), resulting in low hatchability with 12 hatchings only. F2 hatchlings were paired, thus resulting in a hatching rate of 6%



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incubated at 28°C. Results show that the Fisher exact test detected no significant effect of temperature on hatchability: P = 0.3145).

In the incubation of Leopard Gecko eggs, incubation temperature influenced hatching success, incubation period, tail length, and antipredator behaviour. In contrast, variation in hydric conditions did not engender significant phenotypic variation for most traits. However, the humidity had a slightly different effect on the incubation period in males and females. The humidity had a weak interaction with the temperature at nose length and affected body weight. Hatching conditions can significantly affect phenotypic changes in the hatched leopard gecko. However, the lack of a substantial hydraulic effect makes hatchlings less susceptible to fluctuations in water content than thermal conditions. It suggests that it does not react.

Although there have been studies showing the difference between natural and artificial incubation in reptiles, there are still many unknowns about artificial incubation in Leopard geckos that need further research. Only a few research have precisely described the elements that determine high hatchery success in artificial incubation. Other research has suggested that temperature and humidity regulation and a ventilation system affect high hatchery rates in reptiles. (Ashmore & Janzen, 2003)(Booth, 2015)(Martins et al., 2020) (*Performance of Juvenile Tuatara Depends on Age, Clutch, and Incubation Regime on JSTOR*, n.d.) (Sun et al., 2014)(Oh & Kim, 2017).

Moreira and Barata investigated another factor that could influence artificial incubation (2005). They claim that infertile and non-viable fertile eggs within a reptile clutch may reduce the success of the remaining eggs in incubation. Despite the conflicting findings on the significance of fungal infections in nature, the study recommends that further research in reptiles is warranted.

(Mariani et al., 2021) conducted a study closely related to this one. They unveiled a low-cost microcontroller-based poultry egg incubator. Their design is based on modern approaches, such as the automated controlled device, which keeps humidity and temperature stable and enables automatic tray switching. A DHT 11 sensor is connected to Arduino UNO analog pin one and measures temperature and humidity in analog format. It has a relay switch connected to optical pin two, which will activate whenever the threshold value is reached. The two incandescent lights are controlled by relays, which keep them at the right temperature. The 16 x 2 LCD module displays the current temperature and humidity. The results show that 56 of the 60 duck eggs hatch. For chickens, 48 out of 60 eggs hatch. Overall, the hatchability rate of the incubator was 84.06 percent.

Although the study shows a high hatchery rate, it does not apply to reptiles. Incubation in reptiles and poultry differs primarily in terms of egg turning. Egg turning is essential in artificial poultry incubation, but it is not practiced in artificial reptile incubation. In a study conducted by (Aubret et al., 2015), a theory that reptile eggs should not be flipped after oviposition once the embryo has attached itself to the shell's inner membrane was tested, as this could kill developing embryos. Thirty-eight eggs from 32 clutches of the water snake Natrixnaly were utilized in their experiment to investigate the impact of egg turning on embryo metabolism, hatching success, and hatchling phenotype. The study found that while hatching success was unaltered, juvenile Natrixnaly hatchlings born from turned eggs died at considerably higher rates than snakes born from unturned eggs (37.5 percent versus 4.5 percent mortality). According to the findings of this study, eggs should not be moved from their natural posture.

In East Java, an automatic egg incubator was designed to increase hatching success in turtle eggs for wildlife preservation (Sukandar et al., 2020). On the report of their study, natural factors such as high temperatures and sand humidity caused by climate change pose a significant threat to turtle hatchling development. Unstable temperature and humidity also impact embryos, resulting in a hatchling success rate of 40% and a failure rate of 60%. Their incubator is designed with incandescent lamps as the heating element and a water sprayer to provide moisture in the hatching media. When the readings were not following the setpoint, electronic sensors were used to control the on/off functions of the lamps and water sprayer.

During the experiment, a conditioned room with an optimal temperature of 24ºC to 30ºC and a humidity of around 70% is ideal. Based on the study, temperature, the number of eggs, and egg age are all factors that influence the hatching success of turtle eggs. Temperature fluctuations cause the difference in incubation time; the higher the temperature, the faster the incubation period, and the lower the temperature, the longer the incubation period. The incubation period also impacts the hatchery's success; the longer the egg incubation period, the lower the percentage of hatching success.

One distinction in this model is the use of Bluetooth technology. Aside from using android-based microcontrollers, sensors, and an LCD screen, the incubator's control system can be controlled via Bluetooth. Consequently, the experiment shows that during the 46-day incubation period, 27 eggs were incubated from 30 eggs that hatched, indicating that approximately 90% of the eggs could hatch. Researchers concluded that the temperature and moisture detection sensor in the sand that has been determined/regulated increased the system's percentage by up to 90%.

Considering how critical temperature fluctuations were, homemade incubators that rely on room temperature are prone to this dilemma. Despite their inexpensiveness, their operability is limited to specific values. In contrast, incubators available in the market perform well but are relatively expensive. Moreover, (Frischer et al., 2014) mention in their paper that temperature measuring devices, such as sensors, have advantages and disadvantages. Although thermocouples and other resistive-based sensors are less expensive, they have poor accuracy. Voltage-based sensors, on the other hand, such as thermocouples, are more expensive, but their accuracy is relatively high. The cost-efficiency disparity is nearly insurmountable. Moreover, purchasing ready-made incubators in the market is a costly endeavour.

As a solution, the researchers proposed a low-cost fuzzy-based Leopard Gecko egg incubator for improved hatchery rate conditions. This study aims to fabricate a Leopard Gecko egg incubator with an automatic temperature and humidity control



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and monitoring system using a DHT22 sensor as a temperature and humidity gauge. As a temperature and humidity stabilizer, fans, incandescent lamps, and an ultrasonic atomizer are used. The regulation system employs fuzzy logic as a method. Other criteria used in designing and fabricating the incubator model will be discussed further in subsequent chapters.

### *1.2 Theoretical Framework*

The paper is inspired by the workings of Fuzzy sets by Lotfi A. Zadeh and the Principles of Thermodynamics. Laws governing animal welfare are also considered in this study.

(Zadeh) established the theory of fuzzy sets, which gave rise to fuzzy logic. Fuzzy logic is a method for dealing with subjective, ambiguous, and inaccurate assessments and quantifying the linguistic aspect of available data and preferences for individual or group decision-making. Many industrial practitioners and the general public found it applicable, simple to understand, and appealing (Zimmermann, 2001). Fuzzy systems are also robust because the output does not change significantly when the inputs change (*Fuzzy Logic with Engineering Applications - Timothy J. Ross - Google Books*, n.d.)

(Singh et al., 2013) also declare that the fuzzy logic theory is based on relative graded membership and was influenced by human perception and cognition processes. Due to computational perception and cognition, fuzzy logic deals with uncertain, partially accurate information or lacks sharp boundaries. Fuzzy logic enables the inclusion of hazy human judgments in computing problems. It also provides an effective method for resolving multiple criteria conflicts and better assessing options. New computing methods based on fuzzy logic can be used to create intelligent systems.

This study applied fuzzy logic as a control system since the incubator comprises several devices (incandescent bulbs, ultrasonic atomizers, and relays) that operate nonlinearly. In the case of the heating element, an incandescent light bulb will be used. It is common knowledge that an incandescent bulb is a resistive device. The resistance of the tungsten filament used in incandescent lamps has nonlinear characteristics, which means that current and voltage have a nonlinear relationship. Furthermore, the power consumed by the lamp is not proportional to the square of the applied voltage, as it would be if resistance were linear. However, it varies in proportion to 1.6 times the applied voltage. Tungsten filament has a positive temperature coefficient of resistance (Rohilla & Kumar, 2019)

An ultrasonic atomizer controls the relative humidity (James et al., 2003). It employs the piezoelectric effect to convert electrical energy into mechanical energy at a high-frequency resonance, causing the liquid structure to break up. There are conventional methods for calculating the modes in a plate's free vibration, but they are limited to plates with a continuous homogeneous structure with no cross-sectional changes. There are also methods for numerically approximating the modes of vibration; however, for inhomogeneous models, this can be computationally complex. Furthermore, the coupling effect of piezoelectric energy with mechanical energy must be taken into account, making the theoretical analysis and general solution challenging to obtain. Finite element (FE) is a method used to study numerical approximations of piezoelectric phenomena (Guerra-Bravo et al., 2021)

The temperature of the developing embryo is determined by the incubator's temperature, the embryo's metabolic heat production, and the thermal conductance of the egg and surrounding air (Harb, 2010). Most reptiles lay their eggs in underground nests heated by sunlight falling on the ground above. Within such a nest, thermal conditions can vary on small spatial scales (for example, eggs located at the top vs at the bottom of the nest or the center). Even within a single egg, the warmest part is likely to be closest to the heat source, usually the top of the nest (Du et al., 2011).

Convective heat transfer is the transfer of heat by air currents that occurs when a body loses heat through conduction. As a result, when eggs lose heat through conduction to the surrounding air, the air near the eggshell warms and rises, causing cooler air to move near the eggshell in place of the warm air, generating convection currents that aid in heat removal from the egg. Convection currents are required for the egg to continue losing heat by conduction because conductive heat loss does not occur when the air temperature near the eggshell is similar to that of the eggshell (Boleli et al., 2016).

Radiant heat transfer allows the eggs to be heated. The heat generated by incubating eggs in vermiculite does not dissipate. The observed heating causes vapour loss and tends to manifest late in incubation as metabolism raises the temperature of the eggs, particularly late in incubation. The vapour escapes from the egg as the temperature rises (Rimkus, 1996)

The Department of Environment and Natural Resources (DENR) conceptualized and is currently implementing the Philippine Wildlife Resources Conservation and Protection Act. Geckos are protected under Republic Act (RA) No. 9147, also known as the Philippine Wildlife Resources Conservation and Protection Act. They are regulated under the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). Its collection from the wild and trade necessitates an import permit from the DENR's Biodiversity Management Bureau. RA 9147 violations are reportedly punishable by imprisonment for up to four (4) years and a fine of P300,000.00.

Seizure and forfeiture proceedings will be initiated against seized leopard gecko for violating Section 1113 concerning Section 117 of the RA 10863 or the Customs Modernization and Tariff Act (CMTA) and Section 11 of the RA 9147. The seized wildlife species will be immediately turned over to the DENR under Section 8 of Customs Administrative Order No. 10-2020.

Rectangles in the illustration show the presence of observable variables, whereas circles indicate the presence of latent variables (i.e. unobserved and then estimated).

### *1.3 Statement of the Problem*

The main objective of this research study was to design a low-cost Leopard Gecko egg incubator with good hatching rate conditions with the aid of a fuzzy logic-based mechanism.

Specifically, the study addressed the following:



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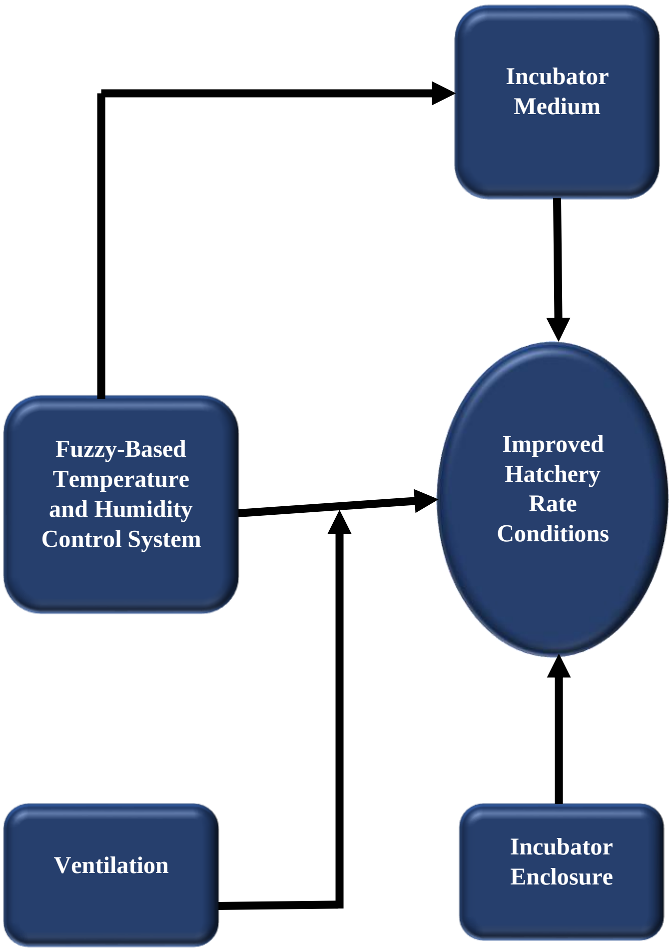


Figure 1. Conceptual Framework

1. List the factors that affected hatching efficiency in Leopard Gecko incubators.
2. Identify the heat energy required to incubate the reptile eggs.
3. To demonstrate the operability of the reptile egg incubator through actual product testing.
4. Calculate the overall performance of the Leopard Gecko egg incubator in terms of responsiveness, accuracy, and safety.
5. To assess the price of the fabricated Leopard Gecko egg incubator to the price of other Leopard Gecko egg incubators available in the local area.

*1.4. Significance of the Study*

*1.4.1 Herpetologist*

This study aimed to provide helpful information on designing a low-cost fuzzy-based Leopard Gecko egg incubator for improved hatching rate conditions and its application in the reptile community. Furthermore, the investigation's findings intend to benefit the following sectors.

*1.4.2 Researchers*

This project design will assist the researchers in utilizing and improving their engineering knowledge and skills.

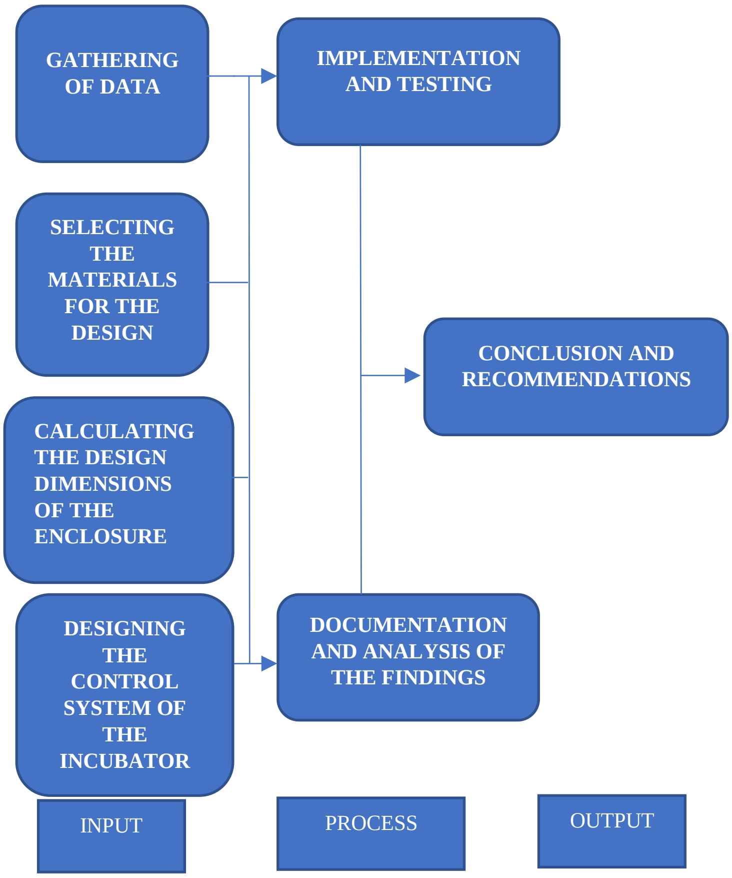


Figure 2. Flow of the study (Input-Process-Output)

*1.4.3 Environmentalists*

This research will aid in the development of specific policies protecting endangered reptile species.

*1.4.4 Herpetoculturist*

This study demonstrated the importance of incubators in the reptile industry.

*1.4.5 Future Researchers*

This study will serve as a focal point for gathering data and locating related studies.

*1.5 Scope and Limitations*

This study focused on finding the primary parameters that affect the performance and condition of Leopard Gecko egg incubators. References such as recent studies, research, and surveys will determine what parameters are required to build a low-cost Leopard Gecko egg incubator for improved hatching rate conditions. Criteria are based upon the performance of the Leopard Gecko egg incubator in terms of maintaining the optimum value of temperature and humidity. Findings in terms of (1) response time, (2) control accuracy, (3) cost, and (4) safety are all taken into account. This study also covers design considerations and calculations for the incubator container, specifically the heat loss during incubation. This project's workings and design parameters are solely for reptiles; specifically Leopard Gecko (Eublepharis macularius.) It does not cover the effects of other egg-laying species exposed to the same controlled conditions as birds and monotremes. The study focused on the performance of the incubator as a whole, not on its components/parts.

This research, however, may have certain drawbacks. First, the study adhered to the purpose of People for the Ethical Treatment of Animals (PETA), since no animals were burned, blinded, poisoned, or hacked up alive in the name of "science," and no Leopard Gecko eggs were used in the study following the research code of ethics. Thus, the results must be evaluated with caution to avoid bias. The second is financial problems. Despite the aim of having a low-cost prototype, the lack of resources such as software programs for designing and simulation and machine shop tools for product fabrication combined with misfortune events that happened is an issue that significantly affects the course of this study. The third is the lack of prior research studies on the topic. Even though there are academic studies regarding reptiles, only limited studies highlight incubation in Leopard Gecko, specifically about its incubator. Lastly, since the prototype operates on a 220V AC power supply, calamities and power interruptions are also factors that can disturb the flow of the study.

### *1.6. Hypothesis*

The hypothesis was tested at a 0.01 level of significance (two-tailed).

*$H_0$:* There is no significant difference between the mean temperature and humidity reading of a fuzzy and non-fuzzy-based incubator.

*$H_1$:* There is a significant difference between the mean temperature and humidity reading of a fuzzy and non-fuzzy-based incubator.

## II. RESEARCH METHODOLOGY

*Research Design*

This study used a descriptive quantitative approach due to its normative nature. The researchers wanted to know if the incubator design could achieve good hatching rate conditions concerning its parameters and if its cost was cheaper than the available incubators. This investigation used surveys and observational methods to collect the data needed to conclude. The observational method referred to actual product fabrication and operability testing. The researchers conducted several simulations and checked if the incubator was executed based on the desired characteristics.

On the other hand, surveys aided in gathering data on the required parameters for a Leopard Gecko egg incubator to achieve high hatching rate results. Moreover, the cost of other fabricated reptile egg incubators was also collected and used as a reference to justify the overall value of the fabricated prototype.

Descriptive statistics and numerical analysis methods were used to derive quantitative observation results.

*Designing the control system*

In designing the Fuzzy-based system of the incubator, the Fuzzy Logic designer was utilized. Input variables (temperature and humidity) while output variables (fan speed) were used as parameters for the system. Since the input values are non-fuzzy, membership functions are used to map the non-fuzzy input values to fuzzy linguistic terms and vice versa. Figure 3 shows the membership functions applied to the humidity system of the incubator and various rule sets formulated and applied to the system to compute the crisp value (output value). The rules implemented are based upon the prior experience of the researchers in terms of incubating Leopard Gecko eggs. The rules are conceptualized to achieve the correct fan speed relative to temperature and humidity values. On the following page is the system's operation process flowchart.

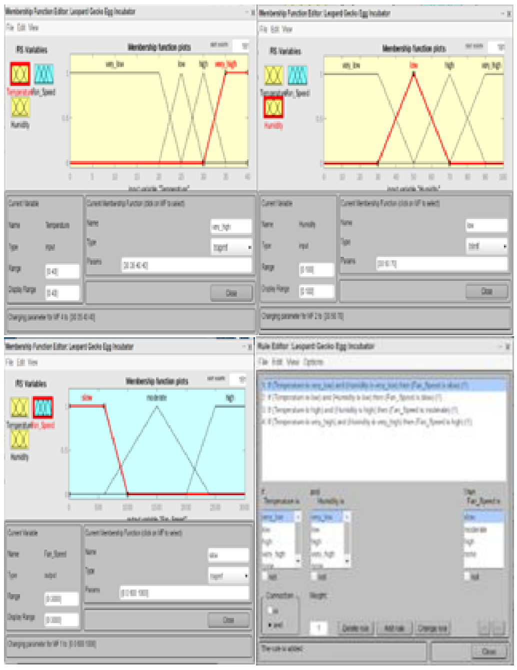

Figure 3. Membership Functions and Rules for the System

*Designing of the Incubator Body*

In designing the incubator body, the researchers applied the principles of heat transfer to calculate the heat required to incubate eggs at the specified capacity of eggs. The formula for heat transfer is:

$$Q = nmCp(T_2 - T_1)$$

Where:

Q = Heat energy in kJ/kW
N = number of eggs
M = mass of Leopard Gecko eggs in kg
Cp = Specific heat capacity in kJ/kg-°C
$T_2$ = Incubation temperature
$T_1$ = Initial temperature (Ambient temperature/Room temperature)

Below is the computation of the number of watts needed by the heat source to produce heat equally to all 30 eggs inside the incubator. According to Abbasnezhad (2015), the $C_p$ for the eggshell of an intact egg is 888 J/kg °C.

Heat Production by the Eggs

$Q_{egg}= nMCp_{egg}(T_2-T_1)$
$= 30 \times 0.16 \times 0.888 \times (40.5-25)$
$= 66.07$ kJ

$$Q_{egg}= \frac{66.07}{10800} x\ 1000 = 6.117 \text{ W}$$



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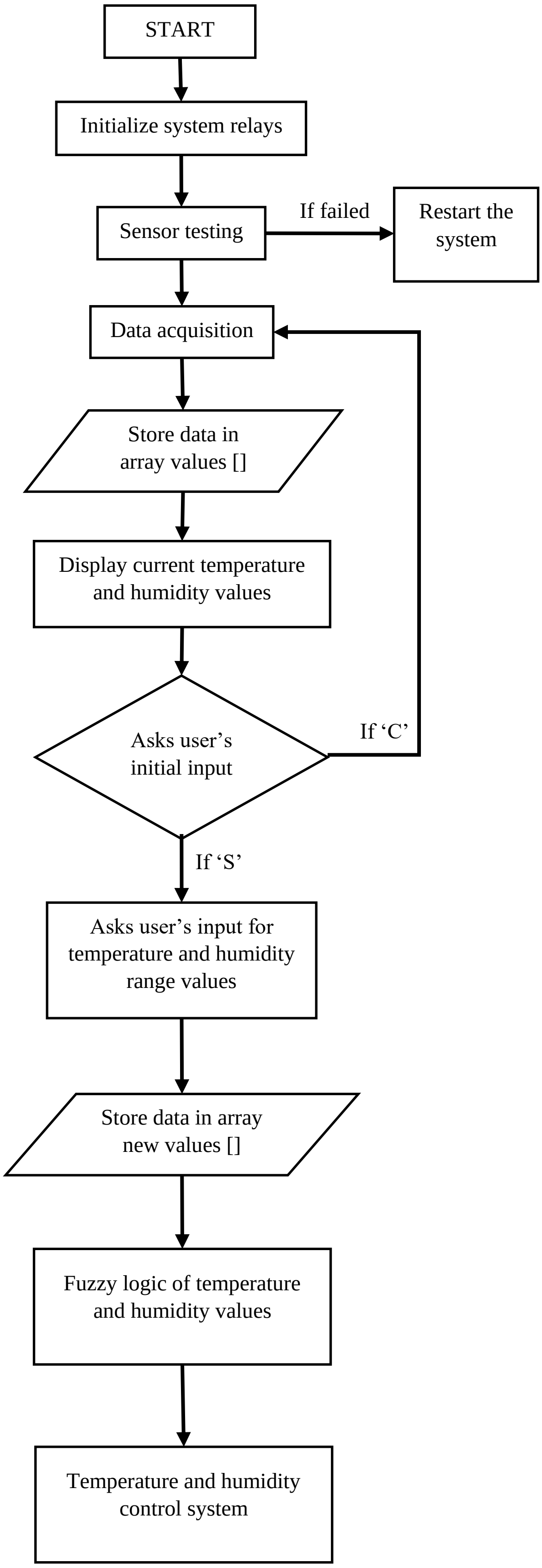


Figure 4. Flow Chart of the Control System

Temperatures of 40.5 °C and 25 °C were assumed to be the maximum and minimum critical temperatures for incubation (Abayarathna et al., 2019).

Heat Energy required to raise the temperature of air from 26.6°C to 35°C

$Q = mCp(T_2 - T_1)$

Where:

Q = Heat energy in kJ/kW

M = mass of air in kg

Cp = Specific heat capacity in kJ/kg-°C

$T_2$ = Incubation temperature

$T_1$ = Initial temperature (Ambient temperature/Room temperature)

$Q_{air}$= mCp($T_2$-$T_1$)

= [ρ x V] ($Cp_{air}$) ($T_2$-$T_1$)

= (1.29) x (0.381 x 0.3302 x 0.483) x (1.005) x (35-26.6)°C

$Q_{air}$ =0.624 kJ

Calculating the heat energy required to raise the air temperature from 26.6 °C to 35 °C was an important note since it signifies the convective heat transfer of air to the eggs. Moreover, it is to secure that our heating element used in the prototype would be sufficient in heating all the eggs equally. Assumptions of 26.6 °C to 35 °C incubation temperature were based on the optimal temperatures for Leopard Gecko egg incubation (Valleley, E. et al., 2002). Moreover, according to Mauldin (2008), the minimum air change in the incubator is about eight times per day or once in every 3 hours. This equal amount of air every 3 hours contains the heat energy required to raise the temperature of eggs from 26.6 °C to 35 °C.

$Q_{air} = \frac{0.624}{10800}\ x\ 1000 = 0.06$ W

For the heat transmission through incubator walls:

$$Q = \left(\frac{K}{S}\right)(A)(T_2 - T_1)$$

Where:

Q = Heat energy in kJ/kW

K = Thermal conductivity of material in *W/m* °K

S = Thickness of the material in meters

$T_2$ = Incubation temperature

$T_1$ = Initial temperature (Ambient temperature/Room temperature)

• Top and Bottom Walls

$Q_{TB}$= [(35-26.6) x (0.13)] ÷ [(0.00635 ÷ 0.035) + (0.00063 ÷ 52)]

=6.0185 x 2

$Q_{TB}$= 12.037 W

• Left and Right Walls

$Q_{LR}$= [(35-26.6) x (0.16)] ÷ [(0.00635 ÷ 0.035) + (0.00063 ÷ 52)]

=7.40738 x 2

$Q_{LR}$= 14.815 W

• Front and Back Walls

$Q_{FB}$= [(35-26.6) x (0.18)] ÷ [(0.00635 ÷ 0.035) + (0.00063 ÷ 52)]

=8.3333 x 2

$Q_{FB}$= 16.667 W

For the total heat loss through incubator walls:

$Q_{total}= Q_{TB} + Q_{LR} + Q_{FB}$ = 12.037 W+ 14.815 W+ 16.667 W = 43.519 W

Minimum quantity of heat required to balance the heat losses in the incubator

$Q = Q_{loss} - Q_{gain}$

Where:

$Q_{loss}$ = the unintentional movement of heat from inside into the outside of the incubator

$Q_{gain}$ = the increase of heat inside the incubator

According to Crombie (2016), practical low-to-medium temperature applications, convection heat loss accounts for atleast 10% of the overall heat loss of a system.

$Q_{required}$ = (43.519 + 0.1) – (6.117 + 0.06)

$Q_{required}$= 37.442 W

A heat source or electric bulb with a 40 W and above power rating is enough to sustain the incubator system. As mentioned in the computation, GI sheet and insulation foam were utilized as incubator enclosure. The justification behind this is that insulation foam adds more insulation, adding more separation between the inside environment of the incubator towards the outside environment. Moreover, polyisocyanurate insulation is an excellent eco-friendly material because of its high thermal efficiency, zero ozone depletion potential, and high recyclable content. Polyisocyanurate insulation foam requires less total thickness in the roof and wall assemblies to provide a specified insulation strength (known as an R-value), lowering overall construction costs while increasing functional building space (Madera, 2015). On the other hand, due to the nature of the incubator, wherein it requires a higher amount of moisture during incubation, Galvanized Iron (GI) sheets were also utilized due to its property that is coated by zinc in order to provide more excellent protection against corrosion for the iron or steel base (GSA, 2016). Furthermore, its primary components, zinc and steel, are natural, abundant, and 100% recyclable.

*Fabrication*

The following were the processes of how the prototype was created:

*Control Unit of the Incubator*

It consisted of the microcontroller (Arduino UNO), LCD, Relay Module, FNG Motor Driver, and Pushbuttons. For the LCD, the *SDA* pin was connected to the *A4* pin of Arduino Uno. Also, the *SCL* pin is connected to *A5*. In the case of the relay module, the connectivity of pins is as follows: *5V-VCC, GND-GND, A0-IN1, A1-IN2*. In the case of the FNG Motor Driver, it was attached to the PMW Pins of the Arduino UNO. The connectivity is *PWMA-Pin 9*, *INA1-Pin 7*, *INA2-Pin 8*, *INB1-Pin 12*, *INB2- Pin 13*, and *PWMB-Pin 11*. Pushbuttons were placed in Pins 2, 3, 4, and 5 of the Arduino UNO.

The microcontroller was then connected to a 12V 4.5A power supply.

*Heat Mechanism of the Incubator*

The primary heat source of the incubator was a 100W light bulb. The bulb was mounted into the incubator through a ceiling receptacle. The bulb was then connected to the relay module. Since the wire utilized was a duplex wire, the first wire of the bulb was directly connected to the *NO* pin of the relay module, whereas its second wire was connected to the first wire of an AC Male Plug. The second wire of the AC Male Plug was redirected into the *C* pin of the relay module.

*Cooling Mechanism of the Incubator*

For the cooling, a Peltier module was utilized. Since a Peltier module has two sides with two different temperatures (hot & cold), the cold side was embarked as the cooling of the incubator. Two heatsinks with different sizes were fastened for the Peltier module, one on each side. The more oversized heatsink was located on, the hotter side, while the smaller heatsink was on the cold side of the Peltier. The hot side of the Peltier was mounted with a 2500 rpm exhaust fan to dissipate the heat absorbed by the heatsink resulting in a colder temperature for the other side. Also, a thermal paste was utilized in joining the Peltier module to the two heatsinks. The fan and Peltier module were connected directly to the power supply (Positive wire to V+, Negative wire to V-).

*Humidity Mechanism of the Incubator*

The humidity source of the incubator was the mist maker and water reservoir. For the mist maker, it was also connected to the relay module. The first wire was connected to the *NO* pin, and the second was connected to the *C* pin. A water basin was put below the incubator chamber for the water reservoir.

*Ventilation System*

Four fans were utilized as the incubator's ventilation system, two intake and two outtake fans. Two intake fans were connected in parallel; then, the positive wire was connected to the *A2* pin while the negative wire was connected to the *A1* pin of the motor driver. The same procedure was performed for the two outtake fans, with its positive wire connected to the *B2* pin while the negative wire was connected to the *B1* pin of the motor driver.

*Incubator Enclosure*

The skeletal part of the incubator was a 1x1 square tube welded together to form the initial structure of the incubator. Afterwards, a GI sheet was employed as the body of the incubator. Before pasting the GI sheet to the skeletal part of the incubator, necessary holes were cut first, such as holes for the fans, ventilation holes, and heatsink. After that, holes were drilled in the square tube and GI sheet at the exact locations. Next, a rivet was used in the holes drilled to combine the square tube and GI sheet. A hinge provided an open/close mechanism for the water reservoir below the incubator. The hinge was drilled and then riveted into the square tube. In the inside part of the incubator, insulation foam was attached using a mist silicone. Moreover, the ceiling receptacle was attached as well as the fans.

*Working Principle of the Mechanism*

Just like any other incubators, the main working principle of this Leopard Gecko egg incubator is to provide artificial incubation at the correct temperature and humidity conditions for Leopard Gecko eggs. The workings of this Leopard Gecko egg incubator mainly start on the *pushbuttons.* It is the mechanism used as data input for the system. It receives and relays the reference value of temperature and humidity to the microcontroller (Arduino). Afterwards, the DHT-22 sensor will record the actual temperature and humidity values inside the

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incubator chamber and compare the result to the reference value. If the actual values are different from the reference value, the microcontroller will turn on the heat and humidity source to equalize the gap between the two values. The control of heat and humidity sources is made possible with a relay. If temperature or humidity exceeds the reference value, the cooling mechanism (fan attached with Peltier module) will turn on. The control of fans is made possible with the utilization of the TB6612FNG motor driver. The turning speed of the fan varies depending on the real-time values recorded by the sensor. This part of the mechanism is where the fuzzy logic is applied. The heat and humidity source both turns off if they exceed or equal the reference value. In terms of data visualization of the incubator, an LCD screen is added to the incubator.

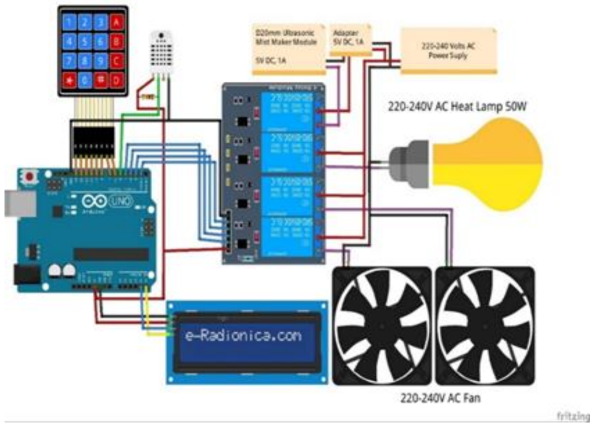


Figure 5. Components for the Temperature and Humidity Control System

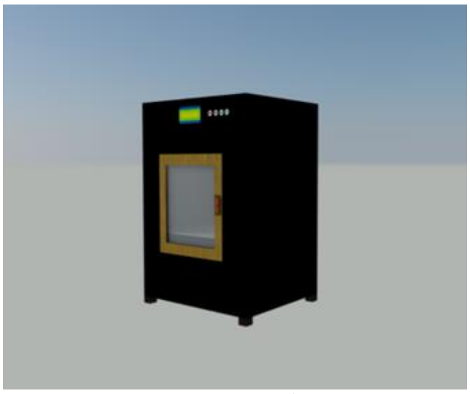

Figure 6. Isometric View of the Incubator

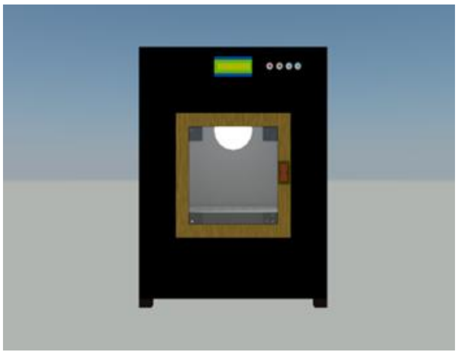

Figure 7. Front View of the Incubator

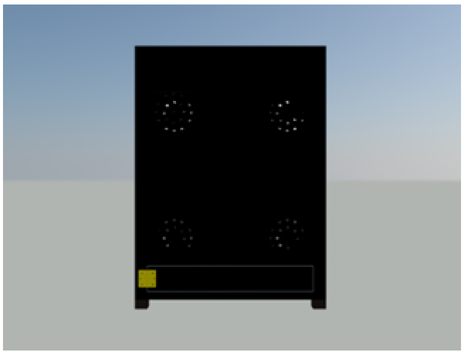

Figure 8. Back View of the Incubator

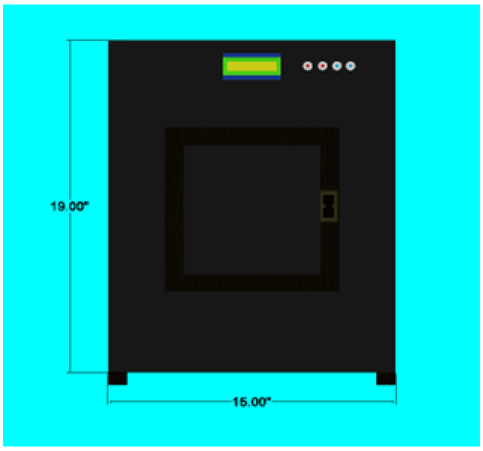


Figure 9. Front View Dimensions

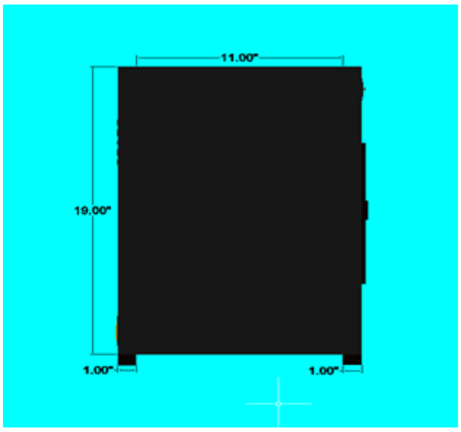


Figure 10. Left Side View Dimensions

*1.6.4 Research Environment*

The actual product testing was carried out in one of the researcher's homes in Lahug, Cebu City. The researchers decided to make this their research setting since the study required day-to-day observation and documentation on the performance of the Leopard Gecko egg incubator. Due to the state of the COVID-19 pandemic, where face-to-face academic and university activities are limited to adhere specific healthcare protocols, interviews were performed online through Google Forms.

*1.6.5 Research Respondents*

The respondents were male/female members of the Cebu Gecko Club. The selected 30 reptile breeders were invited to

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participate because the researchers believed that they had sufficient knowledge to address the issues raised in our study. Furthermore, their prior experiences and knowledge of incubating Leopard Gecko eggs were critical to us researchers. Aside from years of experience, the participants own Certificate of Wildlife Registration (CWR) issued by the Department of Environment and Natural Resources (DENR), indicating their legality in possessing/breeding Leopard Gecko.

*1.6.6 Research Instrument*

The instrument used in the study was a fabricated prototype and surveys. In creating the product prototype, the researchers used Matlab Fuzzy Toolkit first for the simulation in designing the control system. It was utilized to predict the possible capability of the control system to perform the operations. On the other hand, the survey utilized questions that identified their incubators' type, common problems/issues during the incubation period, and incubator cost.

*1.7 Research Procedure*

*Gathering of Data*

Since the participants were chosen based on specific characteristics relevant to the study, purposive sampling, particularly Total Population Sampling, was used. TPS is a research technique in which the entire population that meets the criteria is included in the study (Etikan, 2016). The researchers conducted surveys online through Google forms to collect viable information about the existing reptile eggs incubators used by reptile breeders in our local area. For the survey conducted, 30 respondents were used in this study. The experimentation was divided into two parts: Simulation and Actual product testing. Matlab Fuzzy Toolkit software was used to design and analyze the incubator's control system. In gathering data from the performance of the incubator, Python Shell software was used for simulation. Several simulations were conducted to ensure that the data gathered were accurate.

*Treatment of Data*

In the study, the researchers used descriptive statistics to treat data. The incubator's mean accuracy percentage was the descriptive statistic that summarized the incubator's overall performance in terms of responsiveness and accuracy. The real-time observation was equipped to check the precision and operability of the incubator.

On the other hand, the researchers used the survey results from the respondents to comprehend the various problems associated in their owned incubators. Moreover, it served as the basis for the comparison between the fabricated prototype costs. The mean in terms of cost data was used to conclude the average cost of incubators in the local area. The researchers assessed the impact of the introduced mechanism on the temperature and humidity control systems using Paired Sample T-tests and correlation.

The researchers will use IBM SPSS 26 software for data visualization and computations.

Formula:

$$\bar{x} = \frac{\sum x}{n}$$

Where:

$\bar{X}$ = average mean

$\Sigma X$ = summation of incubator readings (temperature/humidity)

N = total number of readings (temperature/humidity)

*Definition Of Terms*

*DHT-22.* A measuring device is used to read the actual temperature and humidity in the incubator.

*Fuzzy-based.* A fuzzy logic-based temperature and humidity control system.

*Heat energy.* The temperature required to incubate the eggs inside the incubator.

*Herpetologist.* Refers to the zoologists who specialize in the study of reptiles and amphibians.

*Incubator.* An enclosed apparatus that provides a controlled environment for egg hatching.

*Low-cost.* Capable of being purchased or obtained for a low cost.

*Piezoelectric effect.* Certain materials can generate an electric charge in response to applied mechanical stress.

*Polyisocyanurate.* A thermoset plastic, usually in the form of foam, that was utilized as the thermal insulator of our inside incubator.

*Vermiculite.* A sand-like material that is utilized to hold moisture for the humidity of an incubator.

## III. Presentation, Interpretation, And Analysis Of The Study

The researcher surveyed 30 Leopard Gecko breeders and asked the key points to be considered when incubating Leopard Gecko eggs. Table 1 summarizes the key points needed to be considered in incubating Leopard Gecko eggs.

TABLE 1. Existing Incubator Problems

| **Incubator Problems * Incubator Type Crosstabulation** | | | | |
|---|---|---|---|---|
| | | Incubator Type | | Total |
| | | Homemade | Purchased | |
| Incubator Problems | Humidity Control, Temperature Control | 3 | 2 | 5 |
| | Others | 0 | 1 | 1 |
| | Power Outage | 0 | 3 | 3 |
| | Power Outage, Humidity Control | 2 | 8 | 10 |
| | Power Outage, Humidity Control, Temperature Control | 2 | 1 | 3 |
| | Power Outage, Temperature Control | 2 | 2 | 4 |
| | Temperature Control | 2 | 2 | 4 |
| Total | | 11 | 19 | 30 |

| **Others * Incubator Type Crosstabulation** | | | | |
|---|---|---|---|---|
| | | Incubator Type | | Total |
| | | Homemade | Purchased | |
| Others | | 11 | 18 | 29 |
| | None | 0 | 1 | 1 |
| Total | | 11 | 19 | 30 |

As shown in Table 1, a combination of Humidity and Temperature control problems were the most common issues encountered in homemade incubators, with a frequency of 3 or 27 percent. Next to it, with a frequency of 2 or 18 percent, were problems on 1.) Power outage and humidity control, 2.) Power outage, humidity control, and temperature, 3.) Power outage and temperature control, and 4.) Temperature control alone.



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On the other hand, purchased incubators' main issue was the combination of a power outage and humidity control with a frequency of 8 or 42 percent. A power outage follows it with a frequency of 3 or 16 percent. Some problems combined such as 1.) Humidity and temperature control, 2.) Power outage and temperature control, and 3.) Temperature control only obtained a frequency of 2 or 11 percent each. Lastly, one or 5.3 percent of the total breeders with purchased incubators responded that they 1.) Encountered a power outage, humidity control, temperature control simultaneously, and b.) Does have not encountered any problems during incubation (Table 2). In order to narrow down the points to be considered when incubating Gecko eggs, the researchers combined all the frequencies with the same category. Consequently, ranked the most number of occurrences as the top issue surrounding incubators, whether homemade or purchased, shown in table 2.

Based on the table below, Power outage ranked first among the common issues surrounding Leopard Gecko egg incubators with 67 percent, followed by humidity control with 60 percent, and last was temperature control with 53 percent vote.

In checking the operability of the fabricated Leopard Gecko egg incubator, the researchers performed actual product testing. Table 3 presents the summary of the readings during the actual testing of the prototype. Graph 1 shows the real-time data performance of the incubator during operations in terms of temperature reading, while Graph 2 in terms of humidity reading.

TABLE 2. Ranking of Incubator Problems in terms of Frequency

| Problems | Frequency | Percentage | Rank |
|---|---|---|---|
| Power Outage | 20 | 67% | 1 |
| Humidity Control | 18 | 60% | 2 |
| Temperature Control | 16 | 53% | 3 |

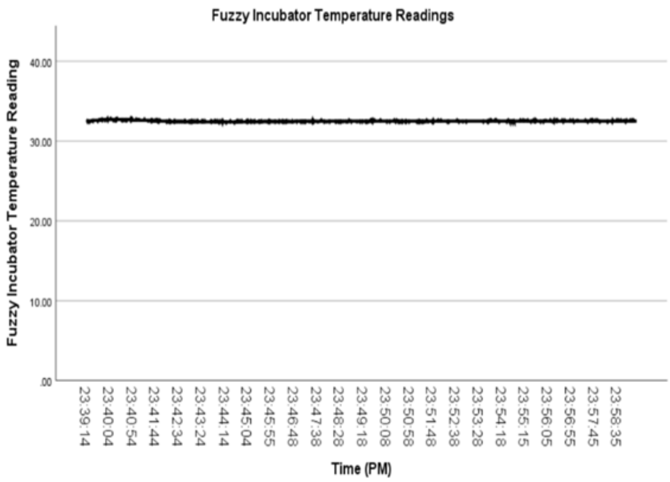
TABLE 3. Summary of Temperature and Humidity Readings

**Descriptive Statistics**

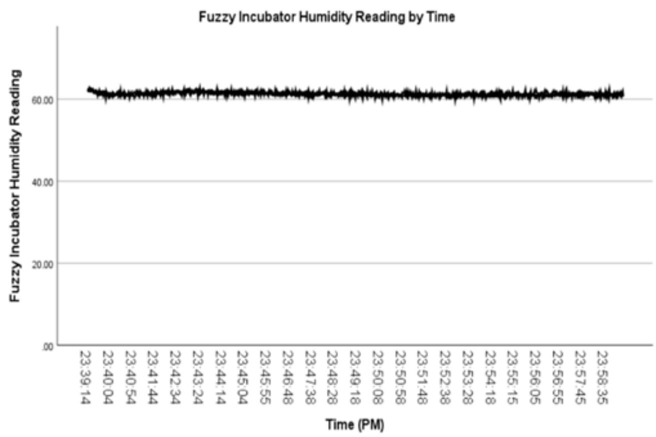
| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Fuzzy Incubator Temperature Reading | 1199 | 30.00 | 33.40 | 31.6154 | .84104 |
| Fuzzy Incubator Humidity Reading | 1199 | 60.10 | 62.50 | 61.2501 | .35335 |
| Valid N (listwise) | 1199 | | | | |

In table 3, it supplies enough data to prove that accuracy of the incubator in terms of maintaining temperature and humidity. For the temperature, a range of 30 to 33.4 °C from the reference value was indicated in the table. Having a standard deviation of 0.84104, it implies that the data/readings were clustered around the mean. For the humidity, it was capable of maintaining an average mean of 60.1 with a minimum and maximum value of 60.1 and 62.5 respectively. Its standard deviation of 0.35 also signifies that the data/readings were clustered around the mean.

As observed in Graph 1, the temperature reading was tested for several minutes with an initial temperature reading of 33°C (relative to ambient temperature). The temperature gradually heats up from the reference temperature of 32°C and reached an equal point of 32°C after 2 minutes. Its coldest or lowest temperature point was recorded at 32.3°C after 15 mins of running the incubator. Observing the performance of the incubator, it executed the design wherein the temperature had an offset value of 2°C before it started heating up again. In this way, the stress on the bulb (heat source) would be lessened, thus increasing the life span of the heat bulb. Nevertheless, a 2-minutes response time is sufficient since the incubator is still starting. In general, the incubator control system performs accurately, but the cooling mechanism of the incubator took a longer time to achieve its reference point.




Graph 1. Real-time Temperature Reading




Graph 2. Real-time Humidity Reading

In terms of humidity, it did not reach its reference humidity value of 80 percent, as shown in Graph 2. The highest humidity reading recorded in the incubator was approximately 62.5 percent, while its lowest range value was approximately 60.1 percent. The mist maker that we designed is not suitable as a humidity source, and it adds too much burden to our system resulting in malfunction or crash. Worst case scenario, it could cause a short circuit and fire to the other components of our incubator. Concerning safety, it is safer to use a bank of water below the hatchlings partnered with incubator medium instead of utilizing the mist maker.

The incubator's overall performance in maintaining the temperature and humidity is summarized in descriptive statistics, as shown in table 3.



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TABLE 4. Fuzzy and Non-Fuzzy Readings Comparison Table

| Paired Samples Statistics | | | | | |
|---|---|---|---|---|---|
| | | Mean | N | Std. Deviation | Std. Error Mean |
| Pair 1 | Temperature Reading of a Non-Fuzzy Based Incubator | 32.4994 | 1292 | .07550 | .00210 |
| | Temperature Reading of a Fuzzy Based Incubator | 31.6633 | 1292 | .84004 | .02337 |
| Pair 2 | Humidity Reading of a Non-Fuzzy Based Incubator | 46.9762 | 1292 | 3.22053 | .08960 |
| | Humidity Reading of a Fuzzy Based Incubator | 61.2373 | 1292 | .35061 | .00975 |

Table 4 showcases the mean averages between a fuzzy and non-fuzzy based incubator. The temperature reading of a Fuzzy-based incubator had a mean value of 31.7°C, with an SD of .8400. In checking the effect of the fuzzy-based mechanism attached to the incubator, a comparison to a non-fuzzy-based incubator was performed. A non-fuzzy-based incubator resulted in a mean temperature reading value of 32.5°C with an SD of 0.08. It implied that prior to the reference value of 32°C, the fuzzy-based mechanism slightly improved the temperature control of the incubator with a difference of 0.3.

For the humidity, it had a mean value of 61, with an SD of 0.35. The non-fuzzy-based incubator had a humidity reading of 47 with an SD of 3.22. These data implied that both failed to reach the reference humidity value of 80. Factor considering the failure is the absence of an incubator medium which is usually used to hold more moisture for the Gecko eggs during incubation. Another is a safety concern.

TABLE 5. Temperature and Humidity Reading Differences

| Statistics | | | Statistics | |
|---|---|---|---|---|
| Humidity difference | | | Temperature difference | |
| Skewness | 1.610 | | Skewness | .054 |
| Std. Error of Skewness | .068 | | Std. Error of Skewness | .068 |
| Kurtosis | 3.470 | | Kurtosis | -.752 |
| Std. Error of Kurtosis | .136 | | Std. Error of Kurtosis | .136 |

In terms of safety, it is hazardous to obtain a high amount of humidity in an area composed of numerous electrical appliances. Because water vapor is trapped inside the enclosures, it corrodes or rusts the metallic and electrical components. The direct result is an electronic component failure, short-circuiting, and premature deterioration of the entire appliance like the heat source (bulb) and DHT-22 (sensor). Nevertheless, a humidity range of 40-60% inside the incubator is still recommended if used, however, with an incubator medium since it acts as a reserve whenever the incubator medium starts to lose its humidity gradually. According to several researches, humidity range of 40-60% is critical and dangerous to Leopard Gecko eggs during incubation. It would be appropriate to maintain 60-90% humidity all the time for the whole duration of incubation process.

TABLE 6. Temperature and Humidity Reading Correlation

| Paired Samples Correlations | | | | |
|---|---|---|---|---|
| | | N | Correlation | Sig. |
| Pair 1 | Fuzzy Incubator Temperature Reading & Non-Fuzzy Incubator Temperature Reading | 1001 | .447 | .000 |
| Pair 2 | Fuzzy Incubator Humidity Reading & Non-Fuzzy Incubator Humidity Reading | 1001 | .132 | .000 |

TABLE 7. Temperature and Humidity Reading T-test

**Paired Samples Test**

| | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Pair 1 | Non-Fuzzy Incubator Temperature Reading - Fuzzy Incubator Temperature Reading | .63706 | .66196 | .02092 | .59601 | .67812 | 30.448 | 1000 | .000 |
| Pair 2 | Non-Fuzzy Incubator Humidity Reading - Fuzzy Incubator Humidity Reading | -14.80569 | 3.16361 | .09999 | -15.00191 | -14.60948 | -148.068 | 1000 | .000 |

The difference in temperature and humidity readings was examined in checking the normality of data, as shown in Table 4. The assumption was considered satisfied, as the skew and kurtosis levels were estimated at (temperature = 0.054 and -0.752) and (humidity = 1.6 and 3.5), respectively, which is less than the maximum allowable values for a t-test (i.e., skew < 2 and kurtosis < 9; Posten, 1984). It will also be noted that the correlation between the two different pairs was estimated at ($r_{temp} = 0.3$, $p < 0.01$ and $r_{humidity} = 0.033$, $p < 0.01$), suggesting that the sample t-tests are appropriate in this case. The null hypothesis of no significance between the two compared means was rejected, $t_{temp}(1292) = 36.6$, $p < 0.01$ and $t_{humidity}(1292) = -159$, $p < 0.01$. Thus, the fuzzy-based mean temperature and humidity reading were significantly better than the non-fuzzy-based mean.

In answering the last question of the SOP, a comparison between the total value cost of the fabricated incubator to the mean cost of purchased and homemade incubators has been examined. As shown in the table below, homemade incubators roughly cost around 2930 PHP, while purchased incubator is around 12250 PHP. Considering the fabrication cost of our designed incubator worth 4600 PHP, we had a lower production cost than purchased incubators while almost near to the production cost of homemade incubators. However, hindrances such as no actual testing of incubation to our prototype were available, making our result insignificant to conclude.

TABLE 8. Incubator Cost Descriptive Statistics

| Descriptive Statistics | | | | | |
|---|---|---|---|---|---|
| Cost | N | Range | Minimum | Maximum | Mean |
| Homemade Incubator | 11 | 6700 | 300 | 7000 | 2927.27 |
| Purchased Incubator | 19 | 24800 | 3000 | 27800 | 12242.11 |
| Fuzzy-based Incubator | 1 | 4600 | 4600 | 4600 | 4600 |

## IV. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

### *Summary*

The study utilized both survey and prototype instruments to gather data. The respondents were 30 Leopard Gecko breeders in Cebu City selected using the purposive sampling method. The statistical tools utilized were descriptive statistics and paired samples T-test.

The study's findings were summarized according to the problem statement:

1. *List the factors that affect hatching efficiency in Leopard Gecko incubators.*
   Whether it is homemade or purchased, any incubator has different issues. Ranking the common problems surrounding Leopard Gecko incubators in our locale area, Power Outage was the leading proponent, with a frequency of 20 or 67% of the total population (N=30). Next was humidity control problems with a frequency of 18 or 60% (N=30). Lastly was the temperature control problem with 16 or 53% (N=30). Overall, these common factors varied from breeders to breeders, but these problems generally existed.
2. *Identify the heat energy required to incubate the reptile eggs*
   The calculation of heat energy required for the incubator was correct since, during the actual testing of the product, the incubator was able to supply the correct temperature necessary for the incubator with a good response time. Assumptions of 26.6 °C to 35 °C incubation temperature was based on the optimal temperatures for Leopard Gecko egg incubation (Valleley, E. et al., 2002).
3. *Demonstrate the operability of the reptile egg incubator through actual product testing.*
   The reptile egg incubator was operable and safe during actual product testing. It could sense the temperature correctly and display it on the LCD screen. Moreover, it had push buttons for changing the incubator's input values/reference values (temperature & humidity).
4. *Calculate the overall performance of the Leopard Gecko egg incubator in terms of responsiveness, accuracy, and safety.*
   *4.1* In terms of responsiveness, the incubator was incapable of maintaining humidity in a short amount of time. Even though it can maintain the humidity, the humidity-producing mechanism was insufficient for the incubator. On the other side, it was responsive to maintaining the temperature, as it achieves the temperature reference value of 32 °C.
   *4.2* The accuracy of the incubator was also evident in the study. The temperature reading of a Fuzzy-based incubator had a mean value of 31.7°C, with an SD of .8400 while non-fuzzy based incubator had a mean temperature reading value of 32.5°C, SD of 0.08. Humidity readings for a fuzzy-based incubator had a mean value of 61, with an SD of 0.35. The non-fuzzy-based incubator had a humidity reading of 47 with an SD of 3.22. The null hypothesis of no significance between the two compared means was rejected, $t_{temp}(1292) = 36.6$, $p < 0.01$ and $t_{humidity}(1292) = -159$, $p < 0.01$. Thus, the fuzzy-based mean temperature and humidity reading were significantly better than the non-fuzzy-based mean.
   *4.3* Due to the results garnered in the study, the incubator design was not safe for incubating the Leopard Gecko egg if the humidity reference value would go beyond or equal to 65%. Reasons include: (1) Results in an electronic component failure, short-circuiting, and premature deterioration of the electrical components like the heat source (bulb) and DHT-22 (sensor), and (2) Humidity ranging 40-60% is the design limitation of the incubator.
5. *Assess the price of the fabricated Leopard Gecko egg incubator to the price of other Leopard Gecko egg incubators available in the local area.*
   The fabricated Leopard Gecko egg incubator's cost was lower than the prices of the available incubators sold in the market while nearly the same as those homemade incubators by other Leopard Gecko breeders. However, due to the lack of actual incubation testing, its true value was still unsettled. Nonetheless, the capability of the incubator to execute according to parameters were prominent in this study.

*Conclusion*

Based on the indicated findings, the following are conclusions derived from the study:

1. Optimum temperature range of 30-32°C and humidity ranging 0-60% is the design limitation of the incubator.
2. An incubator system's precision is mainly affected by the temperature and humidity source of the incubator and its sensor.
3. It is not advisable to utilize a mist maker as a humidity source for this incubator design.
4. Based on performance, it shows slight improvement in terms of responsiveness and accuracy of the incubator.
5. The low-cost fuzzy-based incubator is significant in improving hatchery rate conditions.

*Recommendations*

This study revealed the possible effectiveness of the low-cost fuzzy-based Leopard Gecko egg incubator in improving hatchery rate conditions. The following recommendations are prescribed to improve the results taken in the study.

1. Future researchers may improve the incubator's humidity by utilizing an incubator medium such as vermiculite or perlite.
2. Future researchers may innovate a different type of humidity mechanism aside from a mist maker.
3. Future researchers may employ compressor cycle based cooling system for the incubator to achieve temperatures lower than 29 °C
4. Future researchers may utilize different types of sensors to ensure the precision of the incubator readings.
5. Future researchers may engage the prototype in actual incubation testing to see the incubator's total efficiency in executing a reasonable hatching rate.

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