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An enhancement to the FLC-based baby incubator system using genetic algorithm

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Abstract — This research problem focuses on treating premature babies due to hypothermia, so the baby must be put in an incubator for several days. The conventional intensive care method in premature babies is known as the skin-to-skin care method between mother and child. With the latest technological developments, the method is already based on electrical Internet of Things (IoT) engineering. This research proposes the design of an IoT-based prototype known as a smart incubator. This prototype has been equipped with a real-time monitoring system using the Mamdani Fuzzy inference system control and combined using the genetic algorithm method. The results showed that the ideal temperature range in the smart incubator was 33 °C with an accuracy of 99.97 % and was by the fuzzy membership degree in the range of 29 °C $\leq$ x $\leq$ 37 °C. Furthermore, the ideal relative humidity range in the smart incubator was 60 % with an accuracy of 98.60 % and was by the fuzzy membership degree in the 59 $\leq$ x $\leq$ 65 range. Then, the noise range in the smart incubator is 37.9 dB to 56.8 dB with an accuracy of 96.44 % and has been appropriate at the fuzzy membership degree. At a maximum distance of 50 cm, it takes 8 seconds for the prototype to detect movement as a safety measure.

Keywords – FIS-mamdani, genetic algorithm, smart incubator, IoT.

I. Introduction

A premature birth is a condition where the baby is born at the age of less than or equal to 37 weeks and weighing less than or equal to 2,500 gr, as stipulated by the World Health Organization (WHO) in its regulations [1]–[3]. Observations made by [4]–[6] showed that a premature baby experienced a decreased immunity due to his or her difficulty in adapting to the environment, including some heat loss from the conduction (because the surface directly related to the baby was colder); the convection (due to the baby's movement); the radiation (due to colder objects that were not in direct contact with the baby); the water evaporation (due to the surface of the skin and lungs). Babies born prematurely need some intensive care in an incubator [7], that describes a mother's uterus since the device is ready to maintain warmth stability (*e.g.*, the ambient temperature of the incubator, the baby's temperature, and the humidity around the incubator). When the latest technology of an incubator is applied, it shows that the incubator has been very organized and automated. Moreover, this technology is supported by the transition of a conventional incubator (manual setting of temperature and humidity) into an incubator automatically capable of remotely monitoring the baby based on the Internet of Things (IoT) [8], [9].

An incubator designed according to Marwanto *et al.* [10] is a representation of the function of a uterus. It means that an incubator is supposed to control the surrounding temperature and humidity to support the development of the baby; therefore, a fuzzy logic control (FLC) is employed to create a stable surrounding environment for the baby to maintain his or her body temperature within the range of normal and relatively constant values. In the same year, Azkiyak *et al.* [11] discussed the results of implementing an

Android-based IoT incubator. Next, Azman *et al.* [12] developing an incubator based on IoT focuses on monitoring the temperature and the humidity of the incubator so that the results can still be implemented on a simple test scale. Therefore, Dutta and Anjum [13] explain that the temperature and the humidity are some unpredictably varied factors if one takes into account various cases around the incubator [14], eventually resulting in some output levels controlling the heater and the humidifier.

In 2021, Luthfiyah *et al.* [9] explains the use of wireless fidelity (Wi-Fi) facility to support IoT in a kind of centralized monitoring system shown in one monitor against several infant incubator nodes. Mizanur *et al.* [15] proposes an incubator temperature control design using fuzzy-based proportional integral derivative (PID), so the effective time and overshoot will be obtained to identify the accuracy of the incubator temperature. Furthermore, Alimuddin *et al.* [16] proposes a fuzzy-PID system performance design to regulate the temperature and humidity by comparing the temperature and the humidity outputs in the baby incubators. The results show that the controller successfully achieves and maintains the temperature and humidity setpoints. Therefore, taking into consideration the results of the observed literature review (OLR) that has previously been carried out, a fuzzy inference system (FIS) is the right method for this study aimed at determining various decision factors in the development of an IoT incubator.

In line with the OLR stated above, the results of the research review show that FIS plays a relevant role in the use of IoT. Research in [17]–[19] defines IoT as a concept that combines several things (devices/components) and the ”Internet” facility, so the conventional prototype becomes something that can be managed, monitored, and controlled remotely [20], [21]. Widhiada *et al.* [22] introduces the results of a fuzzy-based prototype in maintaining the stability of the membership function (MF) against 1 input (Temperature and Humidity) with 1 Output (Lights) with lights on/off conditions. Then, the FIS performed by Sumardi *et al.* [23] consists of 1 MF-input (Temperature) to produce an MF-output, namely on/off lightbulbs. Furthermore, Budiyanto *et al.* [24] introduces the prototype results of FIS-Sugeno optimization on the wireless sensor network (WSN) to monitor forest fires consisting of 2 MF-inputs (Temperature and Smoke) producing 1 MF-output (Fire hot spot) then producing four conditions such as Normal, Alert, Standby, and Watch Out conditions.

In 2021, Silalahi *et al.* [25] proposes a new student admission selection system consisting of four MF-inputs (subject scores) resulting in 1 MF-output (passed the selection) including failed conditions, waiting list, continue the test, and passed without test finally displayed in an Android-based dashboard. As having been mentioned above, the research is implemented and is centered on several ambient conditions. It means that this study is aimed at identifying factors that maintain the temperature and the humidity of the baby in the incubator so that he or she feels comfortable and safe in the incubator for a certain period referring to the setpoint (centroid). Thus, this study proposes the development of an IoT incubator using a FIS method. We must keep in mind that a FIS method works under several closed-loop control conditions. It means that it takes a condition that is used as an unpredictable variable to take a certain action. In this case, the FIS-input condition used as the variable is the temperature of the baby moving dynamically. Moreover, the static/fixed conditions are the ambient temperature incubator and moisture incubator to issue a high/low cooling fan incubator action.

Nonetheless, the MF setting on Fuzzy can potentially be automated, so the next proposed solution method is a genetic algorithm (GA) method. [26] was the first researcher to successfully conduct various GA simulations for a premature baby incubator control system to improve the temperature control performance. The approach was analyzing the incubator’s physical phenomena involving its dynamic behaviors by using a recursive least square (RLS) technique so that the output would show that the mathematical model of the predicted incubator was by the measured data whose output identified the temperature case and the appropriate humidity; moreover, it made up a decision on an appropriate reaction based on the conditions occurring in the baby incubator environment [27]. Later, Yeler and Koseoglu [28] produced a baby incubator by using a modular thermoelectric heat pump system (MTEHPS) based on various thermal and hydraulic parameters obtained from the optimization results. The shortcomings and the problems arising in the resistance incubator system were anticipated with an improved thermoelectric system.

Furthermore, Maghfiroh *et al.* [29] states that an incubator designed by using s digital scale as auto-adjustment to the PID Control produced an optimal setpoints achievement condition. Balseca *et al.* [30] states that the Fuzzy PI (Proportional Integral) controller that has been tuned through the GA produces a combination of superior accuracy techniques until the method achieves the parametric identification resulting in a comparison controller through the integral squared error (ISE) and integral absolute error (IAE) indexes. Thus, it can be stated that GA [31]–[33] is a metaheuristic method in which each membership function contained in the FIS becomes a chromosome/individual that has been predicted to strongly support the FIS method in determining the decisions. It means that the MF setting on Fuzzy requires a GA role to improve the fuzzy performance. Therefore, this study results in a dynamic control condition of the high/normal/low setting of the cooling fan based on the closed-loop controller condition that has been locked at the 'baby temperature' resulting in an automatic and dynamic setting of the high/low speed of the cooling fan.

This study is aimed at identifying and controlling the temperature of a newborn baby. The first section presents a global identification of the problem of the proposed study using an FIS-GA method for a premature infant by varying the membership functions of the infant's temperature. The second section contains theoretical studies and mathematical modeling of ladder functions and IoT support. The third section describes the processing results after GA optimizes FIS. Moreover, it is continued with the results of the study to draw some conclusions in the fourth section. Finally, this study contains proof of concept of functions and/or important characteristics analytically and experimentally on a laboratory scale to produce a prototype demonstrated into a new smart incubator model. The monitoring and control process is integrated with the Internet of Things in real-time, with accuracy/precision and simulation of the system approach so that the test results will prove technically feasible.

II. Material and Method

In the second section, theoretical studies and mathematical modelling supporting the implementation of a smart incubators employing an IoT-based FIS-GA method [11], [34]–[36] are discussed. This study has three hypotheses. The first hypotheses is that heat loss factors account for the control system performance testing supporting system decision making [9], [37]. The second hypotheses is heat transfer due to negligible radiation [38]–[40], and the third hypotheses is that the fan curves and the interpolations around the setpoint are accurate enough in various operating conditions resulting in the incubator equation as shown on (1) [41].

$$\begin{aligned} RH_{inc}(n+1) = & \frac{H_{sat} VOH_{air} RH_{inc}}{H_{sat} VOL_{air}} \\ & + \frac{H_{sat} VFRH_{hum}(n+1)}{H_{sat} VOL_{air}} \\ & - \frac{H_{sat} VFRH_{inc}(n)}{H_{sat} VOL_{air}} \end{aligned} \tag{1}$$

Zimmer *et al.* [42] states that the heat transfer through the incubator is measured from the dimensions of the incubator design and by paying attention to the thermal properties that have been adjusted to the baby's body temperature. Thus, based on the calculation of the mass flow rate, Kutz [43] formulates the volumetric flow rate and operating temperature density to obtain the results as shown on (2).

$$dm = \rho VF = \rho VA_{pipe} = \rho V \pi r^2 \tag{2}$$

Furthermore, the convection coefficient through interpolation of its thermal properties, kinematic viscosity (v), followed by the calculation of the numbers Reynolds (R_e), Rayleigh (R_a), Grashof (G_r), and Prandtl (P_r) then produces the equation as shown on (3) - (10).

$$G_r = \frac{g(T_s - T_\infty)d^3}{v^2 Tf} \tag{3}$$

$$R_a = G_r P_r \tag{4}$$

$$Nu_n = \left(0.6 + \frac{0.387 Ra^{1/6}}{[1 + (0.559/P_r)^{9/16}]^{8/27}}\right)^2 \tag{5}$$

$$R_e = (VFD)/v \tag{6}$$

$$Nu_f = 0.197 R_e^{0.612} P_r^{1/3} \tag{7}$$

$$convection\ type = \frac{gr}{R_e^2} \tag{8}$$

$$Nu_{mix} = \left(Nu_f^{3.8} - Nu_n^{3.8}\right)^{1/3.8} \tag{9}$$

$$h = \frac{Nuk}{D} \tag{10}$$

Therefore, the data are collected on the basis of measuring the temperatures ranging from 32 °C to 36 °C [1]–[3] and reading the humidity in the incubator. Furthermore, the materials and methods will be described in the following section.

A. Internet of Things

Shabeeb *et al.* [7] states that a system that goes through Wi-Fi connection is connected to a smartphone or computer application. Furthermore, it is processed by an Arduino microcontroller [44], [45], and the DHT11 sensor and its supporters are displayed on the liquid crystal display (LCD) screen as shown in Fig. 1.

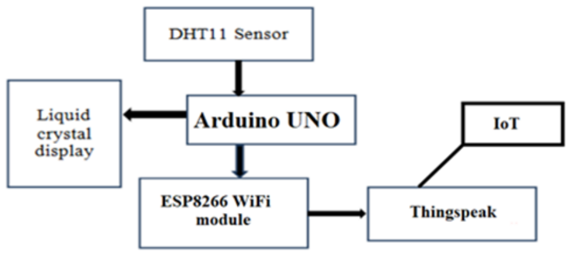

Fig. 1: IoT model-1.

Athavale *et al.* [46] produces a prototype of an embedded device for the real-time monitoring of a newly born baby in an incubator. That device enables an early detection of any potentially life-threatening events and maintains a safe environment for the baby. It is known that the normal temperature ranges from 36.5 °C to 37.2 °C. Therefore, this study is mainly aimed at overcoming any shortcomings and providing an environmentally friendly service to the community as shown in Fig. 2.

Latif *et al.* [47] proposes a smart incubator that can monitor a newly born baby continuously and can

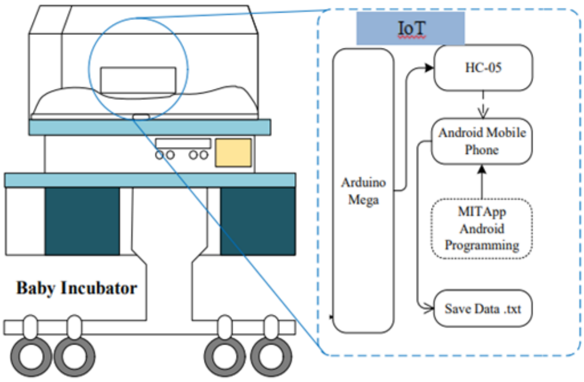

Fig. 2: IoT model-2.

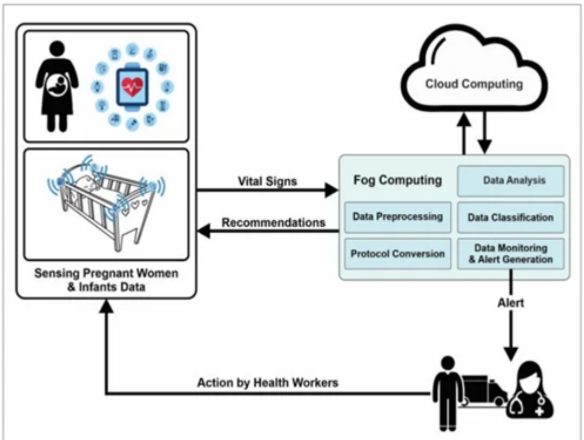

Fig. 3: IoT model-3.

directly transmit the medical data to the cloud storage. The results of that monitoring can be seen from a mobile phone or a computer system in the real time with a displayed accuracy that can easily be understood by a doctor if there are findings related to the baby's health as shown in Fig. 3 [48].

B. Fuzzy Inference System (FIS)

Departing from the global problem and its application, Mamdani's model FIS theory has an opportunity to be developed for the treatment of a premature baby. The FIS-Mamdani method planned in this study consists of fuzzification, rule-based, and de-fuzzification [48].

1) Fuzzification

Fuzzification is a process of changing the non-fuzzy variables into the linguistic variables. In Mamdani fuzzification, either the crisp input or crisp output variables are divided into the fuzzy sets as shown in Table 1.

Finally, based on Table 1, the results of the design of the FIS-Mamdani ladder function equation shown in (11) - (13) are obtained.

$$\mu[x]Temp_{inc} = \begin{cases} Cold = 0 & ; x \leq 0 \text{ or } x \geq 50 \\ Warm = \frac{x-25}{75-25} & ; 25 \leq x \leq 75 \\ Hot = \frac{100-x}{100-50} & ; 50 \leq x \leq 100 \end{cases} \quad (11)$$

$$\mu[x]Mois_{inc} = \begin{cases} Low = 0 & ; x \leq 0 \text{ or } x \geq 50 \\ Ideal = \frac{x-25}{75-25} & ; 25 \leq x \leq 75 \\ High = \frac{100-x}{100-50} & ; 50 \leq x \leq 100 \end{cases} \quad (12)$$

$$\mu[x]Temp_{baby} = \begin{cases} Chill = 0 & ; x \leq 0 \text{ or } x \geq 30 \\ Normal = \frac{x-15}{45-15} & ; 15 \leq x \leq 45 \\ Fever = \frac{60-x}{60-30} & ; 30 \leq x \leq 60 \end{cases} \quad (13)$$

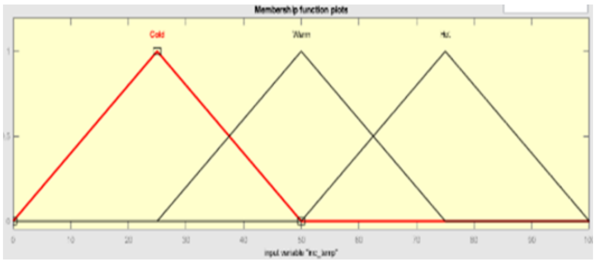

Fig. 4: MF incubator temperature.

Fig. 5: MF incubator moisture.

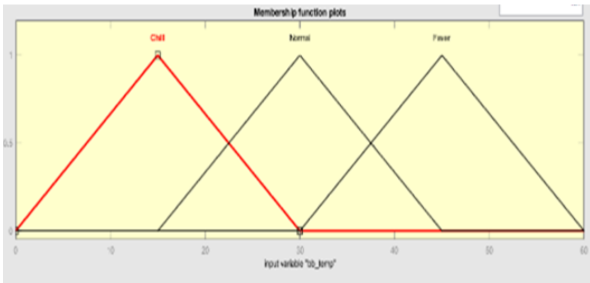

Fig. 6: MF baby temperature.

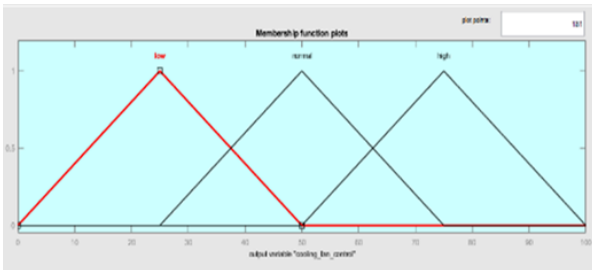

Fig. 7: MF cooling fan.

a. Incubator Temperature Input Variable Membership Function
The incubator temperature input variables are divided into three membership sets, namely $Cold$, $Warm$, and Hot, as shown in Fig. 4.
b. Incubator Moisture Input Variable Membership Function
The input variables are divided into three sets of

Table 1: Membership Function of FIS-Mamdani

No	MF-Incubator Temp	MF-Incubator Moisture	MF-Baby Temperature	MF-Cooling Fan
1	**Cold**	**Low**	**Chill**	**Low**
	MF 1 = 0	MF 1 = 0	MF 1 = 0	MF 1 = 0
	MF 2 = 25	MF 2 = 25	MF 2 = 15	MF 2 = 25
	MF 3 = 50	MF 3 = 50	MF 3 = 30	MF 3 = 50
2	**Warm**	**Ideal**	**Ideal**	**Ideal**
	MF 1 = 25	MF 1 = 25	MF 1 = 15	MF 1 = 25
	MF 2 = 50	MF 2 = 50	MF 2 = 30	MF 2 = 50
	MF 3 = 75	MF 3 = 75	MF 3 = 45	MF 3 = 75
3	**Hot**	**High**	**High**	**High**
	MF 1 = 50	MF 1 = 50	MF 1 = 30	MF 1 = 50
	MF 2 = 75	MF 2 = 75	MF 2 = 45	MF 2 = 75
	MF 3 = 100	MF 3 = 100	MF 3 = 60	MF 3 = 100

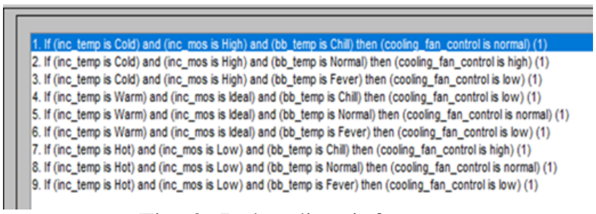

Fig. 8: Rule editor inference.

memberships, namely Low, $Ideal$, and $High$, as shown in Fig. 5.

c. Baby Temperature Input Variable Membership Function
The baby temperature input variables are divided into three membership sets, namely $Chill$, $Normal$, and $Fever$, as shown in Fig. 6.

d. Cooling Fan Output Variable Membership Function
In the cooling fan, the output variables are the actions of the cooling fan. The variables are divided into three membership sets namely Low, $Normal$, and $High$, as shown in Fig. 7.

2) Inference

Inference is an implication stating the process of drawing a conclusion from the rule: If – And - Then. In the Fuzzy Mamdani method, the conclusions are drawn by using the MIN-MAX implication function. Fig. 8 shows a combination of fuzzy rules.

3) Defuzzification

By evaluating the diverse scenarios that may arise from the fusion of T_a (incubator temperature), T_b (incubator moisture), and T_s (baby temperature), the fuzzy system rules are formulated. The set of rules is provided in Table 1 serving as a control system characterized and operated in a regulatory mode. The Fuzzy rules manipulate the hot air flow value depending on the actual T_a and T_s values, so the T_c (the baby's core temperature) can be arranged within the variable random range. For instance, if T_s = $Normal$ (N), T_b = $Ideal$ (I) and T_a = $Warm$ (W), then the flow rate (Q) should be $Normal$.

The crisp output of the Q, as indicated in (14), is obtained by employing the centroid defuzzification scheme [49], [50] to utilize the defuzzified output membership value.

$$Q = \left[\frac{\sum_{j=1}^{j=3} R_j \Phi_j}{\sum_{j=1}^{j=3} \Phi_j} \right] \tag{14}$$

Where R_j represents the centroid of domain j, and Φ_j represents the output of membership of domain j, with j = 1 to 3 (j = 1 is Low, j = 2 is $Normal$, j = 3 is $High$).

The use of the membership functions and Table 1 are as follows. First, let's assume that T_a = 31.5 °C, the 31.5 °C temperature is in the $Cold$ (C) and $Warm$ (W) domain; therefore, it does not contribute to other domains. 31.5 °C cuts the $Warm$ limit by 18.5 and $Cold$ by 6.5.

Next, let's assume that at this point T_b = 31.5 °C, the 31.5 °C temperature is in the Low (L) and $Ideal$ (I) domains; therefore, it does not contribute to other domains. 31.5 °C cuts the $Warm$ limit by 18.5 and $Cold$ by 6.5.

Next, let's assume that at this point, T_s = 33.2 °C. The corresponding membership value can be calculated by using an equation that defines the triangular boundaries of the domain (see Table 1). 33.2 °C cuts the $Normal$ limit by 3.2, and $Fever$ by 11.8 and does not cut in other domains.

Finally, the fuzzy output is then defuzzified by using a centroid defuzzification scheme to calculate the crisp against Q. In the example above, the crisp value (Z) is calculated by using (15).

$$Z = \frac{\alpha_1 x z_1 + \alpha_2 x z_2 + \alpha_3 x z_3 \cdots + \alpha_n x z_n}{\alpha_1 + \alpha_2 + \cdots + \alpha_n} \tag{15}$$

Thus, the result of the crisp value against Q is 2.9378.

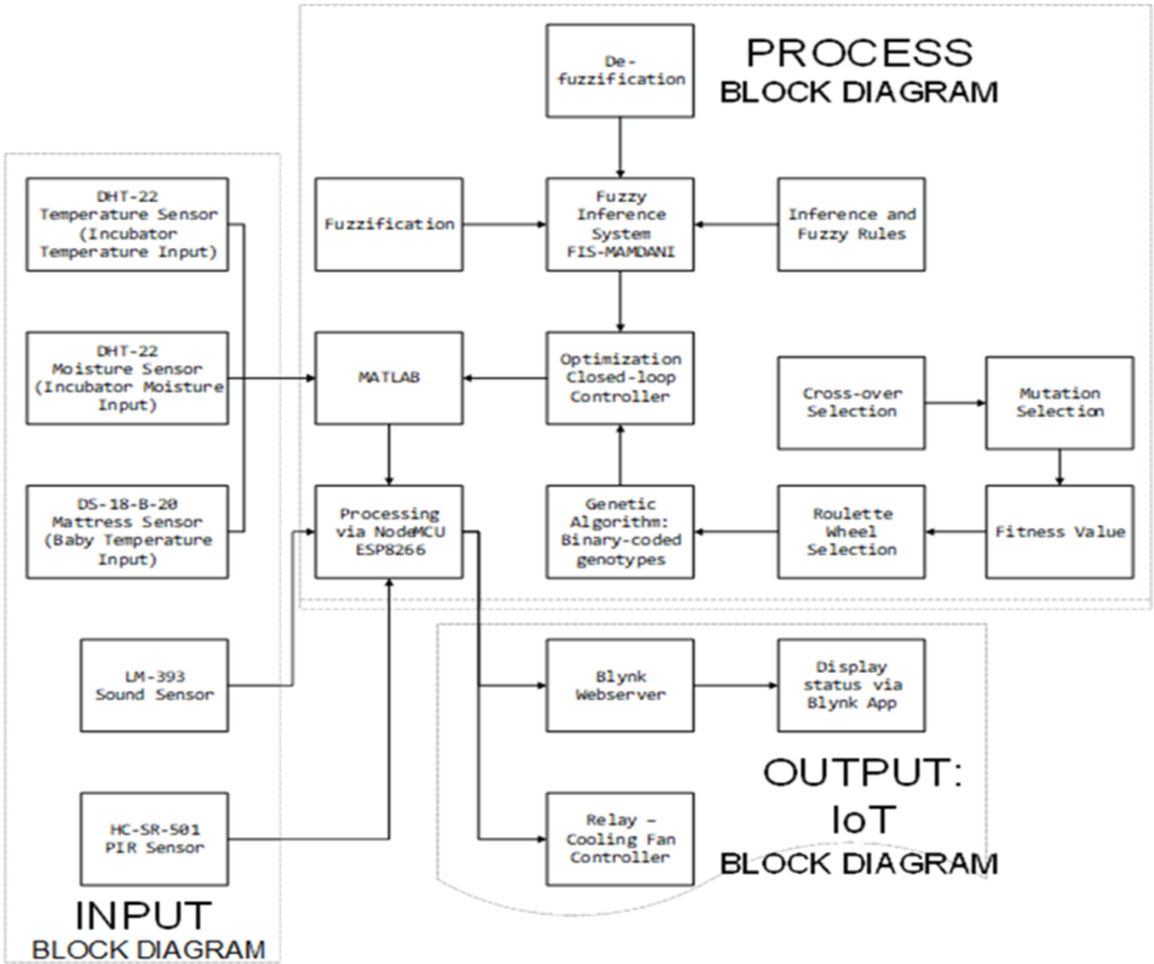

Fig. 9: Research diagram block.

C. Genetic Algorithm (GA)

GA is a random-based optimization algorithm used for solving complex problems. It comprises three fundamental steps: selection, cross-over, and mutation. In GA, solutions are represented as binary strings called chromosomes, with the individual components of chromosomes referred to as genes. It is important to maintain an equal number of genes on each chromosome. The fitness function evaluates the fitness value of each chromosome. The population refers to the collection of chromosomes [51], [52]. GA operates as an iterative process, employing three operators to generate new chromosomes and improve the overall solution.

The selection operators play a crucial role in GA by choosing ”parents” with higher fitness values to generate the next generation of offspring. This study employs the ”roulette wheel” selection operator for this purpose. Additionally, the study utilizes the following operators:

a. Crossover operator: This operator combines the genes of the selected ”parents” to create new offspring. In this study, a single-point method is employed during the crossover phase.
b. Mutation operator: To enhance exploration of the search space, the newly produced chromosome undergoes single or double gene modifications.

The selection operators are theoretically the most influential in directing GA towards an optimal solution and narrowing down the search space. Their aim is to leverage the best attributes of a promising solution candidate, improving it across generations. By following the guidance of GA, the optimization problem at hand can be solved satisfactorily, leading to an acceptable solution [53]–[55].

Connected from the proposed selection operator, the use of roulette wheel selection (RWS), is a method of characterizing the probability of Selection (p_i) on each chromosome (i) in the current population, which is proportional to the fitness value (f_i) as shown in (16).

$$p_i = \frac{f_i}{\sum_1^n f_k} \tag{16}$$

Population size is denoted by n. It should be noted that a well-known drawback of this technique is the risk of GA's too quickly reaching the local optimum

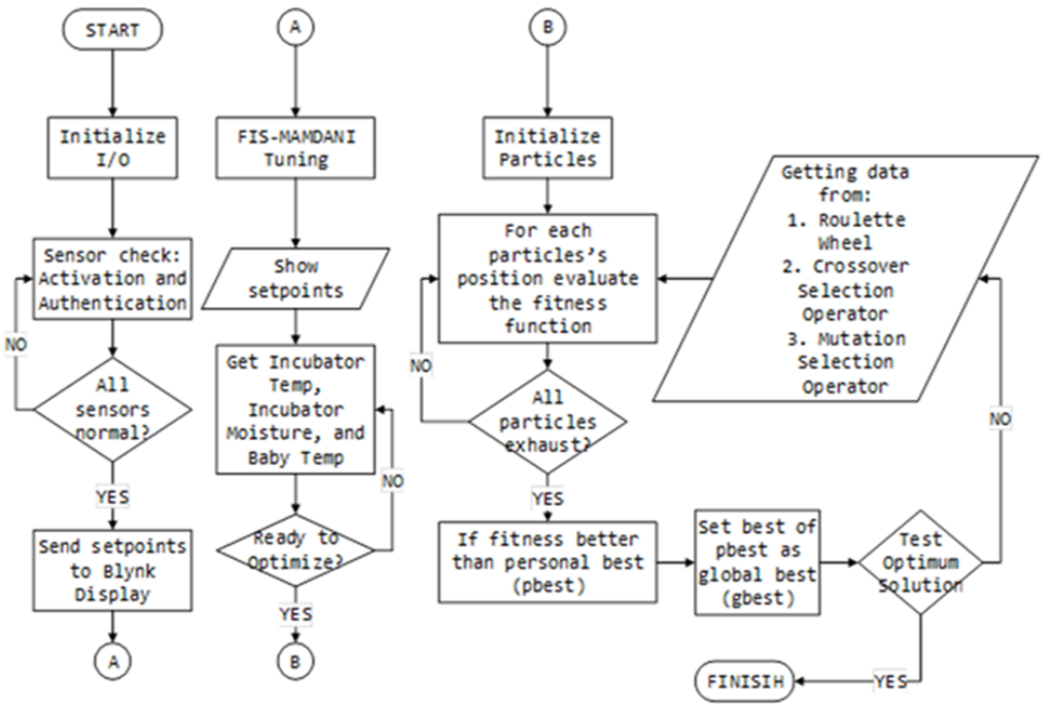

Fig. 10: Flowchart: FIS optimized by GA.

point due to the presence of some dominant individuals who always win the competition and are selected as the broods.

Accordingly, in this study, GA is used due to its success of controlling the baby's temperature which is dynamic; meanwhile, the sensors are installed to perform sensing and readings representing the real conditions of the changing temperature (ambient temperature). It means that if that is the case, it is known that the designed system is a closed-loop controller system.

III. Result

In the third section, the results of the design of the block diagram as shown in Fig. 9 are discussed. Moreover, Fig. 10 shows the design of the GA optimization flow chart against FIS. Next, FIS is processed after the GA optimization to the IoT implementation for a smart incubator design.

A. FIS-GA Optimization

Fig. 11 shows the results of FIS processing after GA optimization by using a minimization scheme. In this study, MATLAB is used to predict the output of the incubator fan cooling speed-based inputs such as the incubator temperature, the incubator moisture, and the baby temperature. A FIS-Mamdani is proposed since the process of drawing its conclusions uses the min-max implication function which is described as follows.

Fig. 12 shows the results of the Mamdani's fuzzification processing. Both crisp input and the crisp output variables are divided into fuzzy sets based on the GA

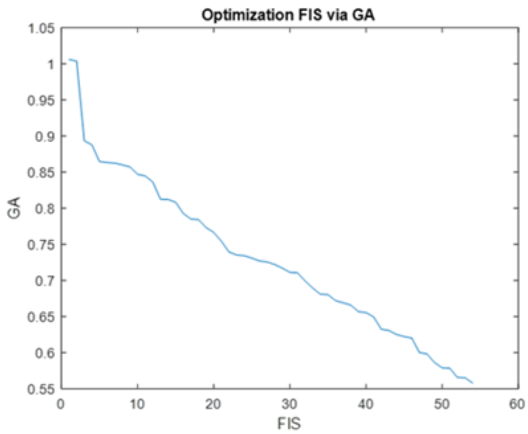

Fig. 11: FIS optimization results using GA.

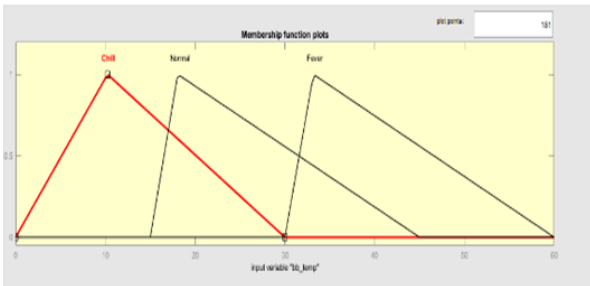

Fig. 12: MF baby temperature.

optimization results where the GA optimization and the value used as a variation called MBF1 – MBF2 – MBF3 are in the baby incubator variable input membership function.

FIS-Mamdani analysis consists of several steps, including:

1) Step 1: Fuzzification function

The fuzzy set of $Warm$ against the detection of the 37 °C temperature in the smart incubator is based on (11). Parameter set up, $\mu[x] = 37$, $Cold$ = 50, $Warm$ = 75, and Hot = 100. Then the results obtained according to (17).

$$\mu[x = 37]\ Warm = \left|\frac{35 - 50}{75 - 50}\right| = \left|\frac{-15}{25}\right| = 0.6 \quad (17)$$

Analysis: The temperature detection result is declared $Warm$ with the MF amounting to 0.6 or 60 %.

The fuzzy set of $Ideal$ against the detection of the 60 % moisture in the smart incubator is based on (12). Parameter set up, $\mu[x]$ = 60, Low = 25, $Ideal$ = 75, and $High$ = 100. Then the results obtained according to (18).

$$\mu[x = 60]\ Ideal = \frac{60 - 25}{75 - 25} = \frac{35}{50} = 0.7 \quad (18)$$

Analysis: Moisture detection results are declared $Ideal$ with the MF amounting to 0.7 or 70 %.

Fuzzy $Normal$ fuzzy set against the detection of the infant's temperature amounting to 36 °C in the smart incubator is based on (13). Parameter set up, $\mu[x]$ = 36, $Chill$ = 30, $Normal$ = 45, and $Fever$ = 60. Then the results obtained according to (19).

$$\mu[x = 36]\ Normal = \frac{36 - 30}{45 - 30} = \frac{6}{15} = 0.4 \quad (19)$$

Analysis: The baby's temperature detection results are declared $Normal$ with the MF amounting to 0.4 or 40 %.

2) Step 2: Inference function

Based on the rules having been applied according to the implication function, nine rules are produced as shown in (20). Moreover, they are clarified by the results as shown in Table 2.

$$\begin{aligned} \alpha - predicate =& \mu_{IT\_Warm} \cap \mu_{IH\_Ideal} \\ & \cap \mu_{BBT\_Normal} \\ =& \min\Big(\mu_{IT\_Warm}(0.6), \\ & \mu_{IH\_Ideal}(0.7), \\ & \mu_{BBT\_Normal(0.4)}\Big) \\ =& \min(0.6, 0.7, 0.4) \end{aligned} \quad (20)$$

3) Step 3: Defuzzification function

After the implication rule is successfully created, the result of the composition of the rules is shown on (21), (22), and (23).

$$(a_1 - 30)/29 = 0.16 \rightarrow a_1 = 34.64 \quad (21)$$

$$(a_2 - 60)/59 = 0.16 \rightarrow a_1 = 69.44 \quad (22)$$

$$(a_3 - 36)/35 = 0.70 \rightarrow a_1 = 60.64 \quad (23)$$

The defuzzification (affirmation) stage is the stage of processing the input numbers obtained from the composition of the rules into the output numbers. The result of the defuzzification process using the centroid method is shown on (24), (25), and (26).

$$M_1 = \int_0^{34.64} (0.16)z\ \mathrm{d}z = 95.99 \quad (24)$$

$$M_2 = \int_0^{69.44} (0.16)z\ \mathrm{d}z = 385.75 \quad (25)$$

$$M_1 = \int_0^{60.5} (0.7)z\ \mathrm{d}z = 1281.08 \quad (26)$$

Hence, the calculation of the centre point in each area is as follows:

$$a_1 = 34.64 \times 0.16 = 5.54$$
$$a_2 = 69.44 \times 0.16 = 11.11$$
$$a_3 = 60.50 \times 0.70 = 42.35$$

Analysis: the defuzzification results of the composition output and the centre point of each area can be shown on (27).

$$\mathbf{Z} = \frac{95.99 + 385.75 + 1281.08}{5.54 + 11.11 + 42.35} = 29.88 \quad (27)$$

Furthermore, MATLAB produces the simulation output as shown in Fig. 13 and Fig. 14.

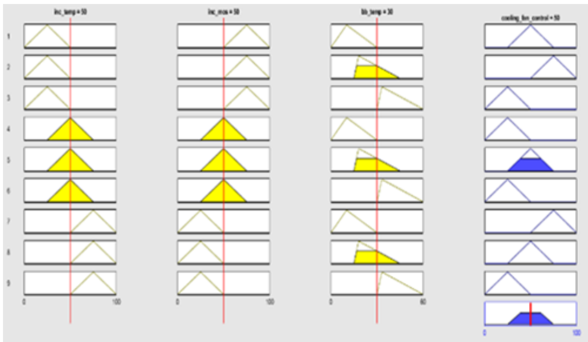

Fig. 13: Output: Rule settings.

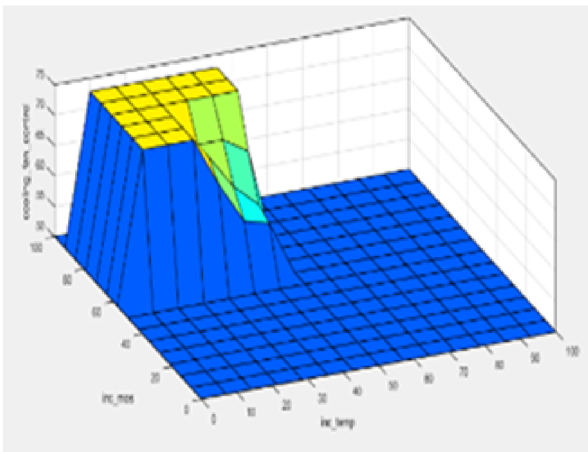

Fig. 14: Output: Surface assignment.

Table 2: Inference Rules on the Internal Smart Incubator

Rule	**Incubator Temperature**	**Incubator Moisture**	**Baby Temperature**	**Cooling Fan**
R01	Cold	High	Chill	Normal
R02	Cold	High	Normal	High
R03	Cold	High	Fever	Low
R04	Warm	Ideal	Chill	Low
R05	Warm	Ideal	Normal	Normal
R06	Warm	Ideal	Fever	Low
R07	Hot	Low	Chill	High
R08	Hot	Low	Normal	Normal
R09	Hot	Low	Fever	Low

Table 3: Inference Rules on the Internal Smart Incubator

Rule	**Incubator Temperature**	**Incubator Moisture**	**Baby Temperature**	**Cooling Fan**
R01	Cold	High	Chill	Normall
R02	Cold	High	Normal	High
R03	Cold	High	Fever	Low
R04	Warm	Ideal	Chill	Low
R05	Warm	Ideal	Normal	Normall
R06	Warm	Ideal	Fever	Low
R07	Hot	Low	Chill	High
R08	Hot	Low	Normal	Normall
R09	Hot	Low	Fever	Low

Table 4: DHT-22 Temperature and Moisture Sensor Test

Rule	**Incubator Temperature**
Microcontroller	AM-2302
Prototype Size	3.3 – 5.5 VDC
Output Signal	Digital Signal
Operating Range	Moisture = $0 - 50°C$
	Temperature = $\pm 2\% RH (\max 5\% RH)$
Accuracy	Moisture = $\pm 2\% RH (\max 5\% RH)$ Temperature = $\pm 0.5°C$
Tested Parameter	Temperature = $30°C$. Error =$\pm 1.9\%$; Accuracy = 98.10%
	Temperature = $33°C$. Error = $\pm 0.3\%$; Accuracy = 99.97%
	Temperature = $35°C$. Error = $\pm 0.4\%$; Accuracy = 99.60%
	Temperature = $37°C$; Error=$\pm 0.24\%$; Accuracy = 99.76% Moisture = 60% ; Error = $\pm 1.4\%$; Accuracy = 98.60%

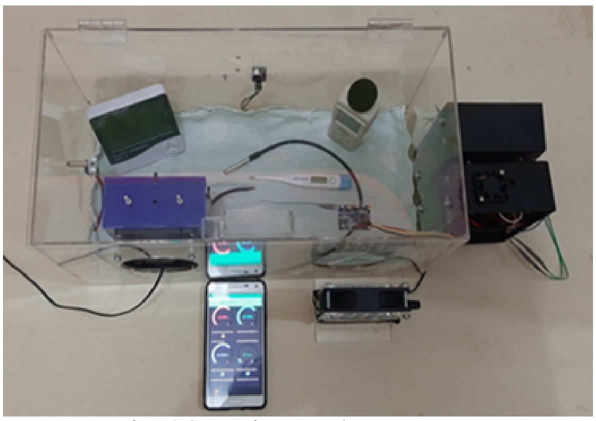

Fig. 15: Design result: prototype.

B. Internet of Things

Fig. 15 shows the final design of the smart-incubator prototype having previously been designed. The data are collected on the smart-incubator prototype with the specification of the overall test results of the smart-incubator system parameters as shown in Table 3.

Table 4 shows the results of the specification test on the DHT-22 temperature and the moisture sensor on the smart-incubator prototype with the measured parameter values.

Table 5 shows the results of the specification test on the DS-18B20 mattress sensor on the smart-incubator prototype with the measured parameter values.

Table 6 shows the results of the specification test on the LM393 sound sensor on the smart-incubator prototype with the measured parameter values.

Table 7 shows the results of the specification test on the PIR HC-SR501 sensor on the smart-incubator prototype with the measured parameter values.

Table 5: DS-18B20 Mattress Sensor Test

Rule	Incubator Temperature
Model	DS-18B20
Power Supply	3.3 – 5.5 VDC
Output Signal	Digital Signal
Operating Range	Temperature = $0 - 50°C$
Accuracy	Temperature = $\pm 0.5°C$
	Temperature = $36.05°C$.
Tested Parameter	Error = $\pm 0.13\%$. Accuracy = 99.87%
	Temperature = $37.31°C$. Error = $\pm 0.53\%$. Accuracy = 99.47%

Table 6: LM393 Sound Sensor Test

Type	Information
Model	IC LM393
Power Supply	3.3–5.5 VDC
Output Signal	Analog Signal
Microphone Sensitivity	Sensitivity can be adjusted
Tested Parameter	Sound test = 56.8 dB. Error = $\pm 4.05\%$. Accuracy = 95.95%
	Sound test = 37.9 dB; Error =$\pm 3.56\%$. Accuracy = 96.44%

Table 8 shows the results of the specification test on the 2-Channel Relay on the smart-incubator prototype with the measured parameter values.

Table 9 shows the results of the specification test on the cooling-fan on the smart-incubator prototype with measurable parameter values.

Table 7: PIR Sound Sensor Test HC-SR 501

Type	Information
Model	HC-SR501
Power Supply	3.3 – 5.5 VDC
Output Signal	Digital Signal
Operating Range	50 cm
Sensitivity	Sensitivity can be adjusted
Tested Parameter	Distance = 10 Cm; Time On = 2 sec Distance = 20 Cm; Time On = 3 sec
	Distance = 30 Cm; Time On = 4 sec Distance = 40 Cm; Time On = 6 sec
	Distance = 50 Cm; Time On = 8 sec

Table 8: Relay 2-channel Test

Type	Information
Model	Relay 2-Channel
Power Supply	3.3 – 5.5 VDC
Rated current main switch	10 Ampere
Tested Parameter	Switch Normally Open 220 VAC (Air Heater)
	Switch Normally Open 9 VDC (Fan)

Table 9: Air Heater and Fan Test

Type	Information
Fan	Power supply = 5 - 9 VDC Dimension = $9 \times 9 \times 2$ Cm Adjustable speed = 500 – 4000 RPM

C. System Analysis

1) Internet of Things-based baby temperature testing analysis

Fig. 16 shows the results of the calibrated data capture. The body temperature measurement is adjusted to the normal limit of the human body namely 36.1 °C. The normal temperature is indicated with the blue led indicator ON, while the body temperature with a fever is indicated with the red led indicator ON.

Fig. 16: Results of IoT-based smart-incubator implementation.

2) IoT based baby voice testing analysis

Fig. 16 shows the results of comparing the noise read by the LM-393 sensor to the AS-804 digital sound level meter sound calibrator. The test is conducted by making noise for one minute. The indicator lamp will turn red (Loud) when the noise level exceeds 45 dB and will turn blue (Normal) when the noise level is less than 45 dB.

3) IoT based baby voice testing analysis

Fig. 17 shows the results of comparing the noise read by the LM-393 sensor to the AS-804 digital sound level meter sound calibrator. The test is conducted by making noise for one minute. The indicator lamp will turn red (Loud) when the noise level exceeds 45 dB and will turn blue (Normal) when the noise level is less than 45 dB.

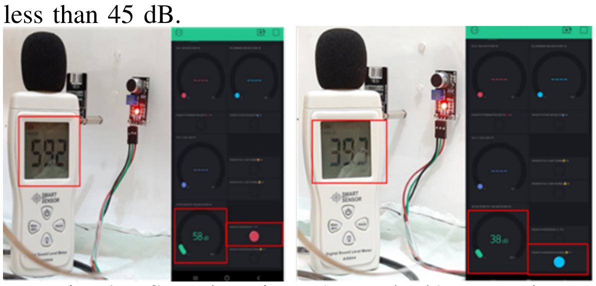

Fig. 17: Sound testing: a) Loud ; b) Normal.

4) Final Analysis

Based on the results of the study, some final analyses are made. They are as follows:

1) The ideal temperature for the baby incubator:
   a) Table 10 shows the results of the temperature test accuracy at 30 °C on the DHT-22 temperature measurement with the Thermo Hygrometer with an average accuracy of 98.13 %.

Table 10: Measurement Result of 30 °C Incubator Temperature

No	Time	Hygro-meter ($°C$)	DHT-22 ($°C$)	Gaps	Acc (%)
1	19 : 24 : 00	30	30.6	0.6	98
2	19 : 25 : 00	30	30.7	0.7	97.7
3	19 : 26 : 00	30	30.7	0.7	97.7
4	19 : 27 : 00	30	30.7	0.7	97.7
5	19 : 28 : 01	30	30.7	0.7	97.7
6	19 : 29 : 01	30	30.6	0.6	98
7	19 : 30 : 01	30	30.5	0.5	98.4
8	19 : 31 : 01	30	30.4	0.4	98.7
9	19 : 32 : 02	30	30.4	0.4	98.7
10	19 : 32 : 02	30	30.4	0.4	98.7
Total		300	305.7	12	981.3
Average		30	30.57	1.2	98.13

   b) Table 11 shows the results of the temperature test accuracy at 33 °C on the DHT-22 temperature measurement with the Thermo Hygrometer with an average accuracy of 99.43 %.

Table 11: Measurement Result of 33 °C Incubator Temperature

No	Time	Hygro-meter ($°C$)	DHT-22 ($°C$)	Gaps	Acc (%)
1	19 : 48 : 01	33	33.1	0.1	99.7
2	19 : 49 : 01	33	33.7	0.7	97, 9
3	19 : 50 : 01	33	33.2	0.2	99.4
4	19 : 51 : 02	33	33.2	0.2	99.4
5	19 : 52 : 02	33	33.2	0.2	99.4
6	19 : 53 : 01	33	33.1	0.1	99.7
7	19 : 54 : 00	33	33.1	0.1	99.7
8	19 : 55 : 00	33	33.1	0.1	99.7
9	19 : 56 : 01	33	33.1	0.1	99.7
10	19 : 57 : 01	33	33.1	0.1	99.7
Total		330	331, 9	1.9	994.3
Average		33	33.19	0.19	99.43

   c) Table 12 shows the results of the temperature test accuracy at 35 °C on the DHT-22 temperature measurement with the Thermo Hygrometer with an average accuracy of 99.58 %.
   d) Table 13 shows the results of the temperature test accuracy at 37 °C on the DHT-22 temperature measurement with the Thermo Hygrometer with an average accuracy of 99.75 %.
2) Data was collected 10 times based on the output of the DHT-22 and Thermo Hygrometer HTC-

Table 12: Measurement Result of 35 °C Incubator Temperature

No	Time	Hygro-meter ($°C$)	DHT-22 ($°C$)	Gaps	Acc (%)
1	23 : 51 : 00	35	35.2	0.2	99.4
2	23 : 52 : 01	35	35.2	0.2	99.4
3	23 : 53 : 01	35	35.2	0.2	99.4
4	23 : 54 : 02	35	35.2	0.2	99.4
5	23 : 55 : 01	35	35.1	0.1	99.7
6	23 : 56 : 01	35	35.1	0.1	99.7
7	23 : 57 : 01	35	35.1	0.1	99.7
8	23 : 58 : 00	35	35.1	0.1	99.7
9	23 : 59 : 01	35	35.1	0.1	99.7
10	00 : 00 : 02	35	35.1	0.1	99.7
Total		350	351.4	1.4	995.8
Average		35	35.14	0.14	99.58

Table 13: Measurement Result of 37 °C Incubator Temperature

No	Time	Hygro-meter ($°C$)	DHT-22 ($°C$)	Gaps	Acc (%)
1	15 : 19 : 01	37	37.2	0.2	99.5
2	15 : 20 : 01	37	37.2	0.2	99.5
3	15 : 21 : 01	37	37.1	0.1	99.7
4	15 : 22 : 00	37	37.1	0.1	99.7
5	15 : 23 : 00	37	37.1	0.1	99.7
6	15 : 24 : 01	37	37	0	100
7	15 : 25 : 02	37	37.1	0.1	99.7
8	15 : 26 : 00	37	37	0	100
9	15 : 27 : 00	37	37.1	0.1	99.7
10	15 : 28 : 01	37	37	0	100
Total		370	331, 9	0.9	997.5
Average		37	33.19	0.09	99.75

1. The incubator's normal limit humidity setting is <60 % RH so that the Fan function will be ON. Table 14 shows the results of humidity measurements, when the humidity is set at 60 % RH, so the percentage of accuracy is 98.58 %.

Table 14: Humidity Measurement Results

No	Time	Hygro-meter (%RH)	DHT-22 (%RH)	Gaps	Acc (%)
1	15 : 19 : 01	60	59.9	0.1	99.8
2	15 : 20 : 01	60	58.9	1.1	98.2
3	15 : 21 : 01	60	59.2	0.8	98.7
4	15 : 22 : 00	60	59.2	0.8	98.7
5	15 : 23 : 00	60	59.2	0.8	98.7
6	15 : 24 : 01	60	59	1	98.3
7	15 : 25 : 02	60	59	1	98.3
8	15 : 26 : 00	60	59.1	0.9	98.5
9	15 : 27 : 00	60	59.1	0.9	98.5
10	15 : 28 : 01	60	59	1	98.1
Total		600	591.6	8.4	985.8
Average		60	59.16	0.84	98.58

3) The ideal body temperature, the method carried

out is to take temperature measurements 5 times at each temperature point with an interval of one minute, the thermometer test is placed in the armpit of the baby, while the DS-18B20 is installed on the mat to detect the baby's body temperature. Normal body temperature measurements have been adjusted to 36.1 °C, while febrile body temperature has been adjusted if it exceeds 37 °C.

a) Table 15 shows the results of testing body temperature in a normal state of 36.1 °C with an accuracy of 99.88 %.

Table 15: Body Temperature Measurement Results: Normal

No	Time	Thermo-meter ($°C$)	DS-18B20 ($°C$)	Gaps	Acc (%)
1	20 : 28 : 01	36.1	36.11	0.01	99.9
2	20 : 29 : 01	36.1	36.12	0.02	99.9
3	20 : 30 : 01	36.1	36.16	0.06	99.8
4	20 : 31 : 00	36.1	36.13	0.03	99.9
5	20 : 32 : 00	36.1	36.13	0.03	99.9
Total		180.5	180.65	0.15	499.4
Average		36.1	36.13	0.03	99.88

b) Table 16 shows the results of testing body temperature in a fever state of 37.5 °C with an accuracy of 99.3 %.

Table 16: Body Temperature Measurement Results: Fever

No	Time	Thermo-meter ($°C$)	DS-18B20 ($°C$)	Gaps	Acc (%)
1	22 : 46 : 02	37.5	36.81	0.69	98.2
2	22 : 47 : 01	37.5	37	0.5	98.7
3	22 : 48 : 02	37.5	37.38	0.12	99.7
4	22 : 49 : 01	37.5	37.48	0.02	99.9
5	22 : 50 : 02	37.5	37.48	0.02	99.9
Total		187.5	180.65	1.35	496.5
Average		37.5	36.13	0.27	99.3

4) Ideal noise range for baby incubators, testing using digital sound level meter AS804 and LM393. The method used is to take noise readings 10 times with an interval of one minute, totalling 10 minutes.
   a) Table 17 shows the test result of noise inside the incubator of 37.9 dB, accuracy of 96.45 %. It means that the sound of the baby incubator is normal.
   b) Table 18 shows the test result of noise inside the incubator of 56.8 dB, accuracy of 95.95 %. It means that the sound of the baby incubator is abnormal.
5) Response time to detect an unsafe baby incubator movement:
   a) The measurement results of the HC-SR501 PIR sensor on several inanimate objects with various distances such as 10 cm, 20 cm, 30 cm, 40 cm, and 50 cm, get a No Detect Notification, LED OFF condition. Output volt = 0, logic = 0, time = OFF. as shown at Table 19.
   b) The measurement results of the HC-SR501 sensor on several living things with various distances such as 10 cm ON time = 2 seconds, 20 cm ON time = 3 seconds, 30cm ON with the time amounting to 4 seconds, 40 cm ON with the time amounting to 6 seconds, and 50 cm ON with the time amounting to 8 seconds, with Motion Detect notification, LED condition ON as shown at Table 19.

Table 17: Noise Measurement Results: Normal

No	Time	AS804 ($°C$)	LM393 (dB)	Gaps	Acc (%)
1	19 : 19 : 01	39.3	38	1.3	96.7
2	19 : 20 : 00	39.3	37	2.3	94.2
3	19 : 21 : 00	39.3	38	1.3	96.7
4	19 : 22 : 00	39.3	38	1.3	96.7
5	19 : 23 : 00	39.3	38	1.3	96.7
6	19 : 24 : 00	39.3	38	1.3	96.7
7	19 : 25 : 00	39.3	39	0.3	99.2
8	19 : 26 : 00	39.3	37	2.3	94.2
9	19 : 27 : 00	39.3	39	0.3	99.2
10	19 : 28 : 00	39.3	37	2.3	94.2
Total		393	379	14	964.5
Average		39.3	37.9	1.4	96.45

Table 18: Noise Measurement Results: Abnormal

No	Time	AS804 ($°C$)	LM393 (dB)	Gaps	Acc (%)
1	21 : 13 : 00	59.2	56	3.2	94.6
2	21 : 14 : 01	59.2	56	3.2	94.6
3	21 : 15 : 00	59.2	56	3.2	94.6
4	21 : 16 : 00	59.2	57	2.2	96.3
5	21 : 17 : 00	59.2	56	3.2	94.6
6	21 : 18 : 00	59.2	56	3.2	94.6
7	21 : 19 : 00	59.2	57	2.2	96.3
8	21 : 20 : 00	59.2	58	1.2	97.9
9	21 : 21 : 00	59.2	58	1.2	97.9
10	21 : 22 : 00	59.2	58	1.2	97.9
Total		592	568	24	959.3
Average		59.2	56.8	2.4	95.93

IV. CONCLUSION

Based on the results of the study, it is found that the study has been completed by successfully proving the concept of function to important characteristics analytically and experimentally to produce a prototype that has been calibrated into an IoT-based smart-incubator model. The temperature of the incubator ranges from 30 °C to 37 °C, and the temperature of the baby can be detected when it ranges from 34.5 °C to 37 °C, Moreover, the humidity can be detected up to the 60 % humidity. The conclusion on the IoT system is drawn;

Table 19: Results of Baby Safety Measurements

Object	HC-SR 501 Status	Distance (Cm)	Volt In (V)	Volt Out (V)	Time (s)
Inanimate Objects	No Detect	10	3.32	0	OFF
Inanimate Objects	No Detect	20	3.32	0	OFF
Inanimate Objects	No Detect	30	3.32	0	OFF
Inanimate Objects	No Detect	40	3.32	0	OFF
Inanimate Objects	No Detect	50	3.32	0	OFF
Living Things	Detect	10	3.32	2.83	2
Living Things	Detect	20	3.32	2.83	3
Living Things	Detect	30	3.32	2.83	4
Living Things	Detect	40	3.32	2.83	6
Living Things	Detect	50	3.32	2.83	8

the response time has reached real-time. For further development, we suggest making a solution such as if, at any time, the IoT is disconnected from the internet, there should be a warning via SMS, so that the network interconnection will directly be checked.

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