

DESIGN AND IMPLEMENTATION OF AN INTELLIGENT SYSTEM FOR TEMPERATURE AND VENTILATION CONTROL IN INFANT INCUBATOR

Ruqayah Nassr Jawad¹, Muntadher Ameen Razzaq², Shaimaa Hatam Rejab³, Hussein Hamed Othib⁴

¹ University of Hillah, College of Engineering Technologies, Department of Medical Devices Technologies

² Al-Mustaqbal University, College of Engineering and Techniques, Department of Medical Instrumentation techniques

³ University of Baghdad, Al-khwarizmi Engineering College, Biomedical Engineering

⁴ Al-Turath University, College of Engineering Technology, Department of Medical Devices Engineering Technology

Abstract:

An infant incubator is a piece of equipment common to pediatric hospitals, birthing centers and neonatal intensive care units. While the unit may serve several specific functions, it is generally used to provide a safe and stable environment for newborn infants, often those who were born prematurely or with an illness or disability that makes them especially vulnerable for the first several months of life. Perhaps the most obvious function of an infant incubator is to protect infants during the earliest stage of life, when they're most vulnerable. As fully enclosed and controllable environments, incubators can be used to protect babies from a wide range of possible dangers. Incubators are fully temperature controlled, shielding infants from harmful cold, and they provide insulation from outside noise, making it easier for them to get plenty of comfortable rest. Incubator environments can be kept sterile, protecting infants from germs and minimizing the risk of infection. The enclosure also keeps out all airborne irritants like dust and other allergens. The cradle of the incubator is a roomy and comfortable surface, so it's possible to leave the infant in place while many examinations and even simple medical procedures are administered. This protects infants from too much handling, which can be a concern in the case of some premature births.

Keywords: Incubator, Temperature, Ventilation

1. Introduction

Maintaining a suitable environment for newborns especially preterm infants is one of the major challenges faced by medical staff in neonatal intensive care units (NICUs). Studies have shown that a significant percentage of infant mortality worldwide is caused by complications related to premature birth, often due to the infant's inability to regulate body temperature and humidity. Because of their underdeveloped organs and poor thermal insulation, premature babies require a controlled and stable environment that provides warmth, humidity, and protection from external factors. This is where infant incubators play a vital role.

This chapter highlights the core problem that motivated this project: the urgent need for a low-cost, reliable infant incubator capable of regulating temperature and humidity especially in developing countries. It also presents the objectives and purpose of the project and gives a general outline of the report's structure and the content of the following chapters. [1].

Problem of Study

Infants who born before 37 weeks of the gestation period are known as preterm or premature babies. Study shows that in every month of birth around 4 million infants die in the world. 25% of the deaths are cause due to complications of prematurity, most often heat and water [1].

Vital organs or enzymes of premature babies grow to the very lesser extent and thus requires special attention to cope with external physical condition like temperature, humidity, light etc. The infant has several disadvantages in terms of thermal regulation. An infant has a relatively large surface area, poor thermal insulation, and a small amount of mass to act as a heat sink.

The newborn has little ability to conserve heat by changing posture and no ability to adjust their own clothing in a response to thermal stress.

Therefore, these parameters are most important to control for saving the lives of infants. In developing country, because the economy is very low so the cost of medical devices should be kept low. Thus, there is a need to develop a low cost incubator, which provides the facilities required for the infants. This paper present a system, which includes system structure, hardware circuits and software program of the incubator for premature infant. The goal of this study is to bring a new project, which will be cost effective with improved usability [1].

According to a new study, cognitive, behavioral, sensory, and motor alterations may develop several years before clinical signs of AD manifest. Unfortunately, the incidence of AD is predicted to affect roughly 74.7 million individuals by the end of the year [2].

Infant Incubators are now used in all hospitals around the world to prepare a suitable ambient condition for the new born. An incubator shown in Fig (1-1) is a device in which an infant may be kept period in a controlled environment for medical care. The incubator should include an AC-powered heater, a fan circulating the warmed air, container for water to add humidity, a control valve through which oxygen may be added, and access ports for nursing care [1].

In the first day's period after birth, the absolute humidity must be monitored so that evaporative heat loss is kept to a minimum as well as water loss through the skin. Heat losses and gains of the newborn body are difficult to monitor. The premature infants lose heat via evaporative, conductive, convective and radiation means [2].

About 28 days after his birth, the newborn was placed in an incubator, where he received clinical care through special glass.

Nurses fed the baby, took his weight, took care of him, performed small procedures, and took an X-ray without repositioning him. To keep the premature baby safe, the inside environment of the incubator was controlled using a variety of control mechanisms [3].

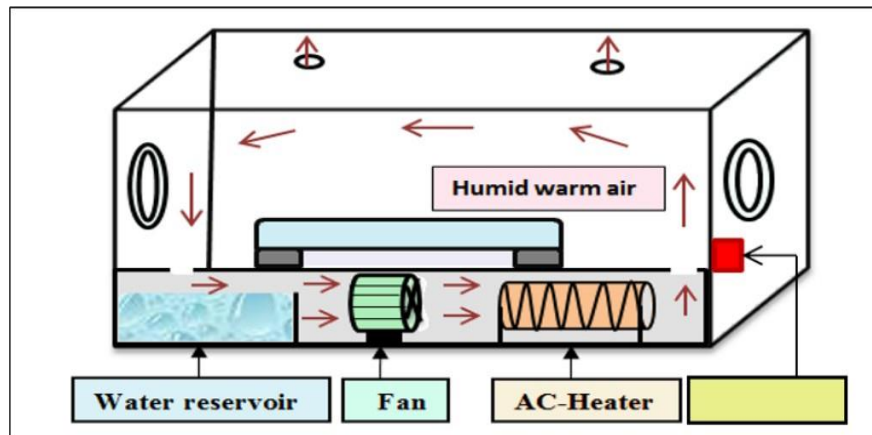


Figure 1. Infant Incubator

Aim of project

Baby Incubator is one of the quite essential life supportive equipment for the premature babies in the hospitals. Unfortunately, there is a lack of low cost infant incubators in the developing world. The aim of the project is to design and develop a microcontroller based temperature control using Arduino Uno kit, temperature control

Project Outline

This project report is divided into five main chapters as follows:

Chapter One: Introduction

This chapter presents a brief introduction to the project, defines the problem, and outlines the aim, objectives, and purpose of the study.

Chapter Two: Literature Review

This chapter reviews previous studies related to infant incubator systems and discusses the principles, components, and methods (software and hardware) used in similar projects.

Chapter Three: System Design

This chapter describes the overall design and implementation of the incubator system, including the hardware components, control methods, and operational flow.

Chapter Four: Results and Discussion

This chapter presents the experimental results obtained from the system, discusses the performance of temperature and humidity control, and evaluates system effectiveness.

Chapter Five: Conclusion and Future Work

This chapter summarizes the project's outcomes, highlights key conclusions, and suggests possible improvements or extensions for future work.

Literature Review

Previous studies

Joshi et al in [1] depicted the development of a Wireless Monitoring System for Neonatal Intensive Care Unit (NICU); which is an isolated room for a premature/weak newborn baby. System provides the environmental condition similar to its mother's belly. Lack of attention to thermoregulation continues to be a cause of unnecessary deaths in the neonatal population.

Salim et al in [2] described the design and implementation of a fully digital and programmable temperature system for the Oxygenize Servo Baby Incubator. The transmitter circuits is also designed and implemented for all the variables of the incubator that are used as control signals like the air temperature sensor (thermistor), baby skin temperature sensor (probe), humidity sensor and air flow sensor. Two modes of operation are implemented in the control algorithm: air or skin mode. The AVR microcontroller is used as a control device and the control program is developed using ATME Assembly language programming. The control unit is sensitive to change of 0.1°C. At start up, based on a unique control strategy, the incubator reaches its steady state in about 14 minutes.

Ameer et al in [3] proposed a novel technique by using Artificial Neural Network (ANN) in order to simulate the premature infant incubator control system by implementing the back propagation

method. Sensors are used to indicate temperature, humidity, and oxygen concentration of the incubator internal environment. Sensors output are entering to the ANN, which identify the corresponding case and decide the suitable reaction upon previous training. The proposed ANN premature incubator control system in all conditions that can occur in the premature infant incubator environment proved right decision technique.

The proposed Artificial Neural Network (ANN) based to control the premature infant incubator system is tested with a set of different cases including extreme cases. The percentage errors of this system are ranged between $1.6e-2$ to $4.6e-2$ in controlling the temperature, between 0.1 to 0.12 in controlling the humidity and are between 0.12 to 1.3 in controlling the oxygen concentration.

Bouwstra et al in [4] designed a Smart Jacket for neonatal monitoring with wearable sensor. The smart Jacket aims for providing reliable health monitoring as well as a comfortable clinical environment for neonatal care and parent-child interaction. In this paper the author explore a new solution for skin-contact challenges that textile electrodes pose. The jacket is expandable with new wearable technologies and has aesthetics that appeal to parents and medical staff.

Kumar et al in [5] has done the study on designing an infant incubator for improved usability. This study helped to arrive at customer needs which were later converted into technical voice for the development of quality functional deployment (QFD), based on which final design specification (PDS) was listed. Five different concepts were generated. Final concept is selected based on Pugh's method of concept selection. From the study the finalized concept has superior usability features compared to that in the present market.

2. Materials and Methods

Components Used

We used many components in this project, the most important of which are:

1. Arduino Nano
2. Breadboard
3. MOSFET
4. LCD
5. Lithium battery
6. Lithium battery holder
7. Buzzer
8. DHT11
9. Fan
10. Heater indicator
11. Wire

Arduino Nano

The Arduino Nano is a small, breadboard-friendly microcontroller board based on the ATmega328P microchip. It is popular for its compact size, ease of use, and ability to integrate into various electronic projects. Here is a quick rundown of its key features and common uses:

Key Features:

1. Microcontroller: ATmega328P (same as the Arduino Uno).
2. Operating Voltage: 5V.
3. Input Voltage: 6-12V (via the barrel jack or VIN pin).
4. Digital I/O Pins: 14 (of which 6 can provide PWM output).
5. Analog Input Pins: 8 (can be used for reading analog sensors).
6. Clock Speed: 16 MHz.
7. Flash Memory: 32 KB (of which 2 KB is used by the bootloader).
8. SRAM: 2 KB.
9. EEPROM: 1 KB.
10. USB Interface: Mini-USB for programming and communication with a PC.

11. Size: 18x45 mm, making it very compact.



Figure 2. Arduino Nano

Breadboard

A breadboard is a tool used for prototyping electronic circuits without the need for soldering. It allows you to quickly assemble and test circuits before committing them to a permanent setup. Here's an overview:

Key Features:

1. **No Soldering Required:** You can insert and remove components easily, which makes breadboards ideal for beginners and rapid prototyping.
2. **Grid Layout:** A breadboard consists of a grid of holes (called contacts or pins) where you can insert electronic components like resistors, capacitors, ICs, and wires.
3. **Internal Connections:** Breadboards have internal connections in rows and columns. The horizontal rows (typically marked with letters) are connected together, while the vertical columns (marked with numbers) are also connected in groups[6].
4. **Power Rails:** On the sides of the breadboard, you typically have long rows labeled as "GND" (Ground) and "VCC" or "+" (for positive voltage). These power rails allow you to distribute power easily across your components[7].
5. **Size and Types:** Breadboards come in different sizes, usually defined by how many rows and columns they have. A full-size breadboard has around 830 tie points, while a half-size breadboard has 400 tie points.

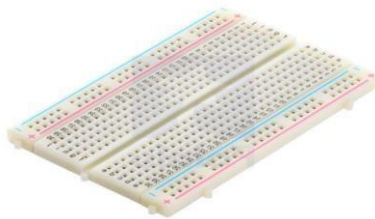


Figure 3. Breadboard

Transistor MOSFE

A metal-oxide-semiconductor field-effect transistor (MOSFET) is a field-effect transistor with a conduction channel made of semiconductor materials. It consists of a source, a drain, and a gate. An insulating layer separates the body and gate.

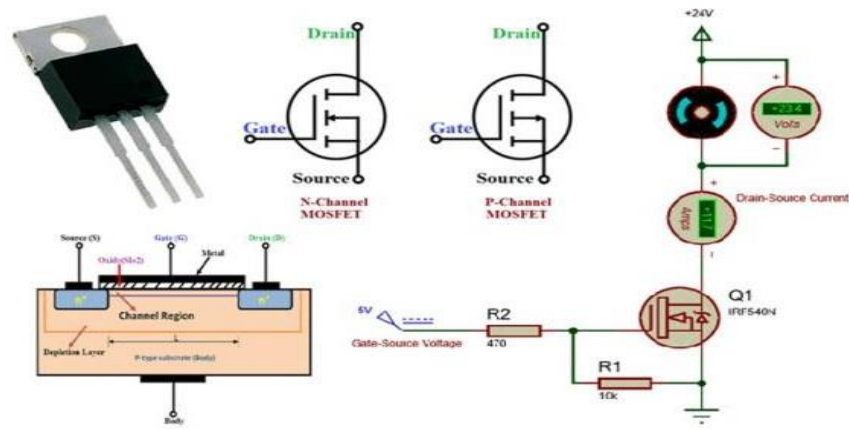


Figure 4. MOSFET

LCD Display I2C 20x4

An LCD Display I2C 20x4 is a Liquid Crystal Display (LCD) screen that has a resolution of 20 characters per row and 4 rows, making it capable of displaying up to 80 characters in total. This display uses the I2C (Inter-Integrated Circuit) communication protocol to interface with microcontrollers and other devices.

1) 20x4 Character Display:

- a. The display is organized in 4 rows and 20 columns, meaning it can show 20 characters on each of the 4 lines.
- b. Commonly used to show text information, such as sensor readings, device status, or menus.

2) I2C Communication:

- a. The I2C protocol allows the display to communicate with a microcontroller using just two wires (SDA for data, SCL for clock), making it more efficient and simplifying wiring compared to parallel communication.
- b. I2C reduces the number of pins required for communication, making it ideal for projects with limited GPIO pins.

3) Backlight:

- a. Many LCD 20x4 displays with I2C come with a backlight feature that can be adjusted or turned off to improve readability in different lighting conditions.

4) Low Power Consumption:

- a. The I2C interface helps to reduce power consumption, especially when compared to parallel LCDs, which require more pins and can be more power-hungry.

5) Controller:

- a. The most common controller used in these displays is the HD44780 or a compatible variant, which manages the display of characters and the handling of commands for controlling the display.



Figure 5. LCD Display I2C 20x4

5) DHT11

The DHT11 is a popular digital temperature and humidity sensor used in various electronics and IoT (Internet of Things) projects. It provides both temperature and humidity readings, which can be useful for applications such as weather stations, environmental monitoring, and home automation systems[8], [9].

1. Temperature Measurement:
 - a. Range: (The DHT11 can measure temperatures from 0°C to 50°C (32°F to 122°F).
 - b. Accuracy: (The temperature readings typically have an accuracy of $\pm 2^\circ\text{C}$).
2. Humidity Measurement:
 - a. Range: The sensor measures humidity levels from 20% to 80% relative humidity (RH).
 - b. Accuracy: The humidity readings have an accuracy of $\pm 5\%$ RH.
3. Digital Output:
 - a. The DHT11 outputs data in a digital format, which means it communicates with microcontrollers (such as Arduino or Raspberry Pi) via a single digital signal.
 - b. The data from the sensor is sent in a serial format, which includes both temperature and humidity readings, and is easily decoded by microcontrollers.
4. Low Power Consumption:
 - a. The DHT11 is designed to be power-efficient, making it suitable for battery- operated applications.
5. Simple Interface:
 - a. The DHT11 only requires a single-wire interface for communication, simplifying wiring and reducing the number of pins needed on a microcontroller.
6. Cost-effective:
 - a. The DHT11 is a very affordable sensor, which makes it popular for hobbyists and educational purposes.
7. Limitations:
 - a. Lower accuracy and range: Compared to other sensors like the DHT22, the DHT11 has a more limited temperature and humidity range, and its accuracy is lower.
 - b. Slow response time: The sensor has a slower sampling rate (typically 1 reading per second).

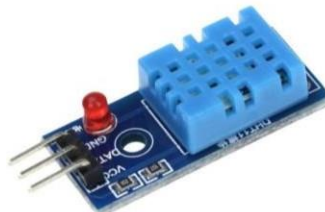


Figure 6. DHT11

6) Buzzer

Electronic component that generates sound through the transmission of electrical signals. Its primary function is to provide an audible alert or notification and typically operates within a voltage range of 5V to 12V. There are various types of these modules that differ in their sound generation mechanisms, operating principles, and applications [10], [11].



Figure 7. Buzzer

7) Jumper Wires

Electronic component that generates sound through the transmission of electrical signals. Its primary function is to provide an audible alert or notification and typically operates within a voltage range of 5V to 12V. There are various types of these modules that differ in their sound generation mechanisms, operating principles, and applications.



Figure 8. Jumper Wires

Methodology

Block Diagram Of The Control Operation:

The air inside the incubator is sensed and used to provide the feedback to the system to be turned on or off actuator according to the set point. In the control system shown in figure (3-8), The sensor samples the output from the system and transforms it into an electric signal that is sent back to the controller. The controller can make any necessary adjustments to maintain the output where it belongs because it is aware of what the system is actually doing. The forward path signal is sent from the controller to the actuator, and the feedback signal, which "closes" the loop—is sent from the sensor to the controller. The system error is obtained by subtracting the feedback signal from the set point (SP) at the comparator and then deducting the actual output (as reported by the sensor) from the desired output (as specified by the set point). The discrepancy between the intended and actual values is represented by the error signal. The controller is always working to minimize this error signal. A zero error means that the output is exactly what the set point says it should be. When the actual value below the desired value the controller is turned on the actuator. In addition, the air inside the incubator reaches the desired value the controller is turns off the actuator.

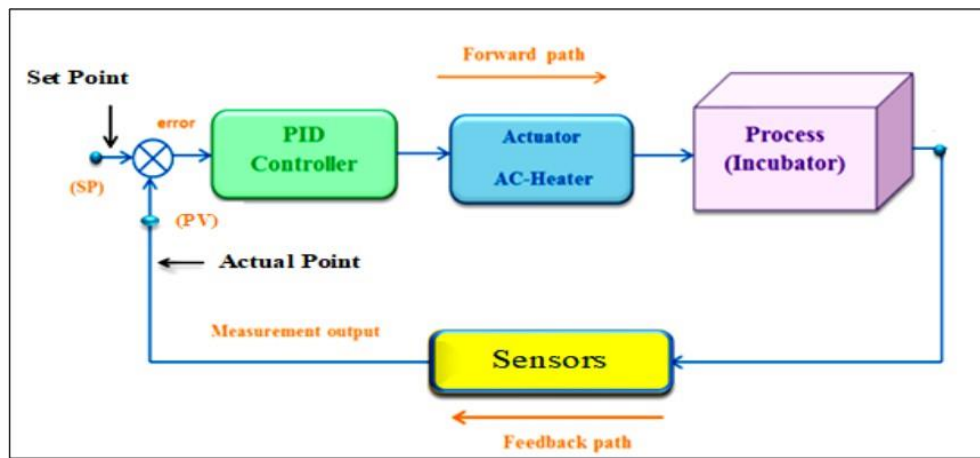


Figure 9. Block Diagram of the Control Operation

On/Off Control

The most basic type of temperature control device is an on-off switch. There is no intermediate state in the device's output; it is either on or off. Only when the temperature exceeds the set-point will an on-off controller switch the output. The output for heating control is turned on when the temperature falls below the set point and turned off when it rises over it. The process temperature will continuously cycle, going from below set-point to above set-point and back below, as the temperature crosses the set-point to alter the output state. To prevent damage to relays and valves in situations when this cycling happens quickly, the controller actions incorporate an on-off differential, sometimes known as "hysteresis." With this differential, the output won't switch on or off again until the temperature reaches a specific point above the set-point. If the cycling above and below the set point happens very quickly, the on-off difference keeps the output from "chattering," or making abrupt, continuous shifts. When precise control is not required, on-off control is typically utilized. It can also be used for temperature alarms, in systems that are unable to withstand repeated energy turns on and off, or in situations where the system's mass causes very sluggish temperature changes. Limit controllers are one unique kind of on off control that's employed for alarm. In order to stop a process when a predetermined temperature is achieved, this controller uses a latching relay that needs to be manually reset.

Proportional Control

Based on a response proportionate to the difference between the variable's present value and the desired process variable (also known as the set point), proportional control is a method used in control systems. When stricter tolerances and prompt response are needed for a process variable, proportional control is employed.

PID Control

Are the most accurate and stable controller. In industrial control applications, a PID controller is a device that controls temperature, flow, pressure, speed, and other process variables. The most accurate and reliable controllers are PID (proportional integral derivative) controllers, which use a control loop feedback mechanism to control process variables. If a process variable is measured and a desired set point is set, the PID controller will compute an error value. When the load fluctuates frequently and the controller is expected to automatically adjust because of these variations in set point, available energy, or mass to be controlled, it is advised for those systems.

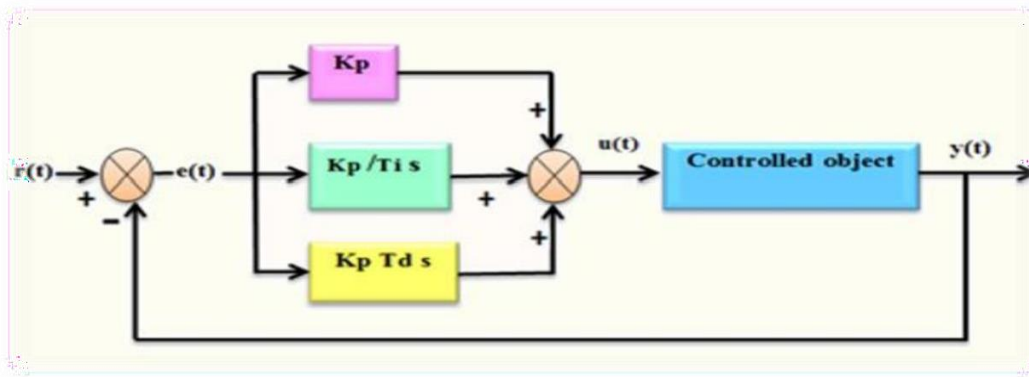


Figure 10. The PID Controller System Structure

Most of the Standards Recommend Two Modes of Operation for Baby Incubators:

- a. Air Temperature Mode.
- b. Baby Skin Mode.

Air Temperature Mode

For many years, this mode has been extensively utilized in the nursing care of newborns. The infant is placed inside a Perspex canopy on a mattress. A heater warms the air inside the canopy, and a fan continuously moves air around. The incubator operator adjusts a thermostat that regulates the air temperature inside the canopy. Once the nurse determines that a baby needs care in an incubator, she has to decide on the right air temperature. Table (3-1) displays the average temperature required to create a suitable thermal environment for a healthy naked baby being cared for in an incubator.

Table 1. Average Air Temperature Needed for Healthy Baby

Birth-weight (kg)	35°C	34°C	33°C	32°C
1.0-1.5	For 10 days	After 10 days	After 3 Weeks	After 5 Weeks
1.5-2.0		For 10 days	After 10 days	After 4 Weeks
2.0-2.5		For 2 days	After 2 days	After 3 Weeks
Greater than 2.5			For 2 days	After 2 days

Baby Skin Temperature Mode

Adhered to the skin of the body, the temperature sensor is a thermistor probe. Because it detects the temperature of the baby's skin rather than the air, the heater heats the air until the skin temperature of the baby is reached. The infant can cool down and vice versa if their skin temperature drops below the predetermined level, which is achieved by lowering the power supplied to the heater and raising the air temperature.

Table 2. Baby Skin Temperature

Birth-weight(kg)	Abdominal skin temperature °C
Less than 1.0	36.9°C
1.0-1.5	36.7°C
1.5-2.0	36.5°C
2.0-2.5	36.3°C
Greater than 2.5	36.0°C



Figure 11. Final design

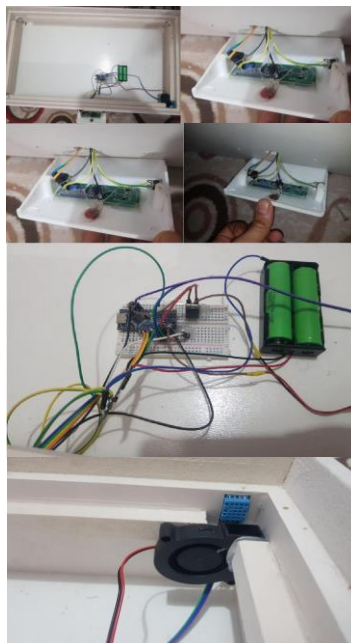


Figure 12. final design (inside and outside)

3. Results



Figure 13. LCD Display Showing Temperature and Humidity

As shown in the figure above, the LCD screen displays the environmental conditions inside the infant incubator. The measured temperature is 24°C, and the relative humidity is 19%. These values were obtained using integrated sensors connected to a microcontroller-based monitoring system.

The temperature reading of 24°C is within the acceptable range for infant incubators, which typically aim for a controlled environment between 22°C and 34°C depending on the infant's condition and gestational age. However, the relative humidity reading of 19% is considered low, as the recommended humidity level for neonates is usually between 40% and 60% to reduce trans epidermal water loss and maintain skin integrity.

This data indicates the importance of implementing an automatic control system to regulate both temperature and humidity within the incubator, ensuring a stable and safe environment for newborns.



Figure 14. LCD Display with Heating System Activation

In this figure, the LCD screen displays a temperature of 18.30°C and a relative humidity of 51% inside the infant incubator. The drop in temperature below the recommended threshold has triggered the heating system, as indicated by the illuminated red LED above the display. The system is

programmed to activate heating when the internal temperature falls below 20°C to maintain thermal stability for the infant. The observed humidity level of 51% is within the recommended range (40–60%) for neonatal care, helping to ensure adequate moisture and reduce the risk of dehydration. This result demonstrates the responsiveness of the automated control system, which helps preserve optimal conditions for newborns by reacting to environmental changes in real-time.

4. Conclusion

We used an incubator that was damaged, so we made some modifications to it and repaired it, and we worked on putting a control circuit outside the incubator so that some of the tools used would not be affected by the temperature. Temperature 37.20 The heater was automatically disconnected from work and the temperature inside the incubator was stable for about 15 minutes and we could have had the temperature stable for more than that, but because of the incomplete insulation well. After the temperature decreased, the cutting circuit was automatically started again, due to the temperature inside the incubator being lower than the required degree until the heater is disconnected faster because it is in a state of heating faster than the start of its operation because it has been heated up.

Frequent power outages are a problem in developing nations like ours, and they must be fixed for the incubator to keep running. To run the incubator in such circumstances, a battery backup has been proposed. An alternative source of the required power is a solar panel.

Therefore, the work being done now opens the door to designing and creating a full incubator that has the potential to save lives. An infant incubator that utilizes the Internet of Things is also suggested in order to remotely monitor and regulate the incubator's environment, including humidity and temperature. The outcomes of the experiment demonstrate that this system is capable of managing the intelligent baby incubator system in real-time and with reliability. Based on the analysis, the infant incubator intelligent control system should have a stable and reliable security module

Suggestions for Future Work

Many researchers and companies are trying to develop Peltier coolers that are both cheap and efficient. If such type of Peltier elements are developed we can also introduce it in Infant incubators, future incubators should minimize heat loss from the neonate and eddies around him/her. An unresolved issue is exposure to high noise levels in the Neonatal Intensive Care Unit (NICU).

Strategies aimed at modifying the behavior of NICU personnel, along with structural improvements in incubator design, are required to reduce noise exposure. Light environment should be taken into consideration in designing new models of incubator

References

- [1] O. A. Bajeh and O. J. Emuoyibofarhe, "A fuzzy logic temperature controller for preterm neonate incubator," in *Proc. 1st Int. Conf. Mobile Computing Wireless Communication, E-Health, M-Health and Telemedicine (MWEMTeM)*, 2008, pp. 158–173.
- [2] M. Zahran, M. Salem, Y. Attia, and A. Eliwa, "Design and implementation of a digital control unit for an Oxygaire Servo Baby Incubator," *Journal of Power Electronics*, vol. 8, no. 2, pp. 121–130, 2008.
- [3] P. Dong, G. Bilbro, and M. Y. Chow, "Controlling a path-tracking unmanned ground vehicle with a field-programmable analog array," in *Proc. IEEE/ASME Int. Conf. Advanced Intelligent Mechatronics*, Jul. 2005, pp. 1263–1268.
- [4] N. S. Joshi, R. K. Kamet, and P. K. Gaikwad, "Development of wireless monitoring system for neonatal intensive care unit," *International Journal of Advanced Computer Research*, vol. 3, no. 3, Sep. 2013.
- [5] M. Salim, "Design and implementation of a digital control unit for an Oxygaire Servo Baby Incubator," *Journal of Power Electronics*, vol. 8, no. 2, Apr. 2008.
- [6] Ghada M. Amer and K. Aubidy, "Novel technique to control the premature infant incubator system using ANN," in *3rd International Conference on Systems, Signals & Devices*, vol. 1, Mar. 2005.
- [7] L. Louis, "Working principle of Arduino and using it as a tool for study and research," *International Journal of Control, Automation, Communication and Systems (IJCACS)*, vol. 1, no. 2, 2016.

- [8] Y. Lee, C. Chiu, L. Jhang, and C. Santiago, "A self-reliance assistive tool for disable people," in *Proc. 3rd Int. Conf. Control and Robotics Engineering (ICCRE)*, 2018, pp. 26–30.
- [9] M. Banzi, *Getting Started with Arduino*. O'Reilly Media, 2009.
- [10] J. Hughes, *Arduino: A Technical Reference, Handbook for Techniques, Engineering's, and Makers*, 1st ed. O'Reilly Media, 2016.
- [11] SainSmart, "Arduino Introduction," 2013. [Online]. Available: www.sainsmart.com