# Design and Development of Portable Incubator

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# Copyright Statement

# Acknowledgements

First of all, I am thankful to Allah the Almighty. I would like to express special thanks of gratitude to my parents as they always supported me and never let my passion die out. I can never pay back for their endless love and care. I am greatly thankful to my wife as she always helped me a lot in every difficult situation and remained a source of inspiration. I am also very thankful to my family members who always stood behind me and supported me.

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*Dedicated to my beloved parents, family members and especially my wife*

# Abstract

The care of preterm babies which are born before 37 weeks of gestation are utmost importance. The preterm are also known as high risk infants as the baby is not fully mature to handle the external environment as the lungs are also not fully developed. As per World Health Organization report, every year 15 million babies are born around the globe. The death rate of these babies is much higher in under developed countries like Pakistan.

In fact, the most significant conclusion from latest research is about the physical environment of preterm infants is that each infant should have a ‘microenvironment’, which can be individualized to needs of the specific child as per gestational age and health condition. In some extent, the incubator can serve as mother’s womb and also helpful in protecting neonate from infection.

In this project, a low cost, efficient and reliable infant incubator is developed and fabricated locally which gives stable levels of temperature and humidity so that the preterm or premature neonate have similar conditions as in the mother’s womb. The humidity and temperature are monitored through very reliable sensors. Microenvironment is achieved inside infant chamber using PID (Proportional Integral Derivative) controllers. The whole system is being continuously monitored using multiple alarms and protections to ensure patient safety.

The humidity is generated by using active Mist Ultrasonic transducer which is more efficient and stable than the conventional steam-based system, having faster response to acquire higher value of humidity.

The performance of the developed incubator is comparable to any CE marked product which gives encouragement to develop the product locally at much cheaper price and thus can be helpful in enhancing life expectancy of premature neonates especially at rural and remote areas having limited health care facilities.

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# List of Abbreviations

| | |
|---|---|
| **PID** | **Proportional Integral Derivative** |
| **WHO** | **World Health Organization** |
| **IOT** | **Internet of Things** |
| **SSR** | **Solid State Relays** |
| **S.D** | **Standard Deviation** |
| **RH** | **Relative Humidity** |

# 1 Introduction

## 1.1 Background

Preterm or Premature babies are Infants who born before 37 weeks of the gestation period. To cope up with external environment, preterm baby requires surroundings exactly similar as in the mother's womb[1]. In fact, mammals have the definite advantage of homoeothermic i.e. nearly having a uniform body temperature, regulated independent of the environmental temperature. It is also point of consideration that at this stage, vital organs of preterm babies are either not fully developed or grown to the very lesser extent and thus needs special care to cope with external environment like humidity, temperature, light and $O_2$ level. The infant has poor thermal regulations having relatively large surface area and poor thermal insulation[2]. The newborn has a little ability to adjust to thermal stresses. The conditions may get worsened by illness or adverse conditions such as hypoxia (below normal levels of oxygen) as lung at this tender age may not be fully functional. So preterm baby needs to be given the similar environment as in the mother's womb infants by keeping in a device known as incubator. An incubator is a small box like device in which an infant may be kept in a controlled environment for medical care. The latest research concludes that preterm infants to be provided with `Micro Environment' as per the infant gestational age and needs. So, an infant incubator provides stable levels of temperature i.e. around 37 ºC, relative humidity and oxygen concentration as per the requirement of baby[3].

The cost of reliable portable infant incubator giving stable environment is quite expensive. However, the product with all these facilities can be developed / fabricated locally at fairly less price which will not only be reliable but more efficient.

## 1.2 Problem Statement

Humidity and temperature are inversely proportional to each other. Maintaining stable temperature as per preterm age inside infant incubator is challenging especially at high humidity. In incubator, system response and stability of these parameters define the efficacy of design as well as efficiency of feedback control algorithm implemented. The incubator with highly stable performances are although available in the market but are relatively expensive and many health care centres especially at rural and remote areas cannot afford to buy these life saving devices.

## 1.3 Objectives of Thesis

Thesis work was mainly focused around the following objectives:

**A.** Design & manufacture of complete portable incubator including Core Base Assembly, Trolley and Canopy.

**B.** Design and development of Electronic Interface based on Microcontroller including protections and alarms.

**C.** Integration and validation of design.

**D.** IOT based real time monitoring of critical parameters i.e. Air Temperature, Skin temperature and Humidity.

### 1.4 Significance of Study

The main idea is to design and fabricate a reliable and efficient, low cost infant incubator locally. The hardware design is based on predicate device i.e. Infant Incubator IP-100 Care Vision (CE Marked). The electronic interface consists of Arduino Mega to monitor and control the temperature and humidity parameters inside the infant chamber to give accurate micro-environment as in mother's womb. The system is more efficient as it is based on ultrasonic based humidifier instead of steam based conventional steam heaters having inherent limitations. The ultrasonic humidifiers are more efficient, having faster and stable response and allows attaining of high humidity in less time frame. The temperature and humidity are controlled independently using PID (Proportional, Integral and Derivative) controllers which is a feedback control system. The microcontroller also allows to set air temperature of inside chamber, baby skin temperature and humidity as per the need of preterm according to age and conditions. The microcontroller also monitors the output of various sensors continuously and generate alarms and indicate faults in case of any issue. Overall system is a very robust, reliable, efficient and user friendly and gives a low cost solution.

### 1.5 Thesis Overview

First chapter deals with the motivation and background of the work done. In the Chapter2, there is description of phenomena of thermal regulation in infant, physical route of heat loss, physiology of cold response, historic perspective of infant incubators and finally latest trends in infant incubators. The Chapter 3 deals with the methodology used to design and fabricate the device and experimental protocol being implemented. The Chapter 4 shows the results acquired for validation of appropriate working of device and in the last Chapter 5 conclusion and future works are discussed in detail.

# 2 Literature Review

## 2.1 Introduction to Preterm Birth

The statistical data shared by WHO (World Health Organization) shows that 15 million infants born each year around the globe are preterm and this figure is continuously rising. It is also alarming to note that complications arising due to preterm birth are a leading cause of deaths in children under 5 years of age[4]. In 2015, 1 million children around the world died due to preterm complications. As per WHO, Preterm is defined as "Babies born alive before 37 weeks of pregnancy are completed". Preterm is further sub-categorized into following[5]:-

**A.** Extremely Preterm (born before 28 weeks of pregnancy).

**B.** Very Preterm (Born between 28 – 32 weeks of pregnancy).

**C.** Moderate to Late Preterm (Born between 32-37 weeks of pregnancy).

## 2.2 Preterm Birth Rate and Pakistan

Pakistan is 4th country in the world after India, China and Nigeria having greatest number of preterm birth-rate[6]. 16 children (approximately) out of every 100 children in Pakistan are born premature However, reason of preterm is generally attributed to multiple pregnancies, genetic influence, infections and chronic diseases like high blood pressure, diabetes etc. Outcomes of preterm birth can be improved in the light of WHO's guidelines which include timely intervention provided to mother to increase the chances of survival and health outcomes i.e. steroids injection before birth, Magnesium Sulphate for neurological health[7], antibiotics on breakage of her water before labour onset as well as intervention for newborn infant i.e. **Thermal care,** provision of Oxygen and feeding support etc so that mother's womb like environment can be provided which will definitely increase the chances of survival.

## 2.3 Temperature Regulation of the Premature Neonate

The infant falls in the category of homeothermic mammal which means that even very premature infant will respond adaptively to changes in the surrounding environment. The response of infant may not be sufficient to maintain core body temperature even in moderately temperature environments[8]. When the core body temperature of premature infant falls below 36° C (96.8° F), the morbidity (poor somatic and brain growth) and mortality rates increases and if this temperature falls below 31° C (88.7° F) which is moderate to severe hypothermia, result in declining of blood pressure and heart rate[9]. Therefore, incubator is the best solution to keep the neonate body within normal range so that energy of baby is used in development instead of producing heat.

## 2.4 Cold Stresses and Neonate

The most stressful cooling event upon infant birth is evaporative heat loss. But at the same time, severe non-evaporative heat loss can also be problematic[10]. Exposed body surface area of neonate is much larger as compared to metabolically active body mass. It means that heat dissipating area of very premature infant is about 5 to 6 times greater in proportionate to an adult. Moreover, smaller size of infant also poses limited thermal storage. Apart from this, premature infant skin also contributes to excessive heat loss as it provides little insulation and allows rapid heat transfer from core to body surface. The neonate lacks the layer of keratinized epidermal barrier surface (outermost cell layer – dead cells) which also contribute in increased evaporative heat loss. Lastly, thermogenesis response (shivering and non-shivering thermogenesis) of neonate is also compromised due to low brown fat stores. The hypoxia in premature infant also reduce mitochondrial oxidative activity which also result in decrease non-shivering thermogenesis.

## 2.5 Physical Routes of Heat Loss

### 2.5.1 Convection

When ambient air temperature goes below infant's skin temperature then convective heat loss occurs[11]. Convection can be natural (flow of heat from skin to air due to temperature difference) or forced convection. In forced convection, the movement of air takes away the heat from baby skin. The heat loss depends upon difference between baby skin and air temperatures as well as air flow speed. The effect of forced convection in disrupting the microenvironment of warm, humid air layered near an infant's skin usually is not appreciated in the nursery, where drafts, air turbulence, and consequently heat loss can occur within the relatively protective environment of an incubator.

### 2.5.2 Evaporation

An extremely premature infant can experience evaporative heat loss in excess of 4 Kcal/kg/hour[12]. The evaporation in infant is due to passive transcutaneous evaporation of water from baby's skin. This transcutaneous evaporation or insensible water loss increases exponentially with decreasing body size and gestation age[13]. This evaporation rate accelerates in presence of high temperature with low relative humidity. The highest evaporation occurs in neonates during first week of life and this loss maybe higher than radiant losses (Hammarlund et al, 1986)[14].

### 2.5.3 Radiation

Transfer of heat from infant's skin to cooler surroundings walls via infrared electromagnetic waves is known as Radiation. The gradient of heat loss in radiation is proportional to temperature difference between baby's skin and surrounding environment. The radiant heat loss is also affected by infant's posture or reducing the radiating surface exposed. In normal relative humidity (around 50% RH), baby experience ambient body temperature determined 40% by air temperature and 60% by wall temperature[15].

### 2.5.4 Conduction

Conductive heat loss occurs when infant's skin comes in contact with surrounding cooler surfaces and it depends on the conductivity of the surface material and its temperature[16]. Usually babies are nursed on insulating mattresses and blankets that minimize conductive heat loss.

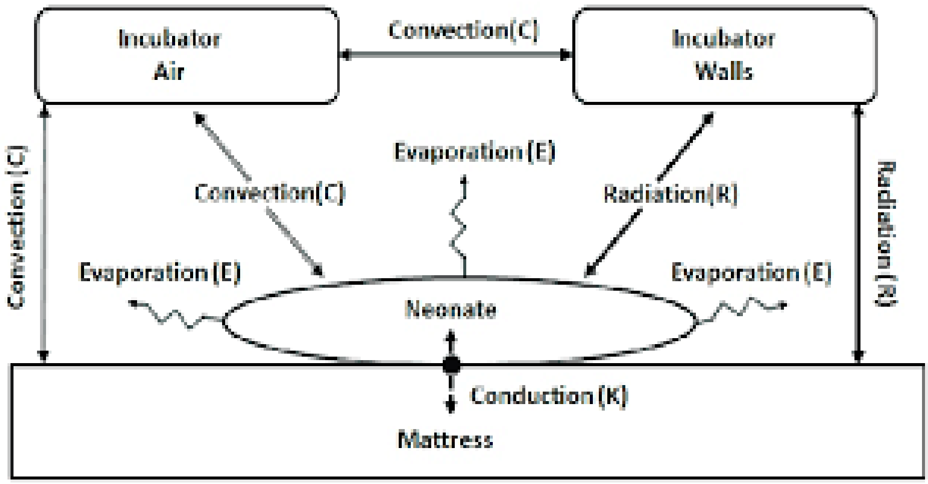


Figure 1: Heat Losses - Incubator

## 2.6 Physiology of Cold Response

### 2.6.1 Afferents

Neonate homeothermic response is generated when the sensation of cold temperature starts. There are two sensitive areas which are temperature sensitive. One is skin and second site is hypothalamus. However, cold sensations are sensed by skin well before the core sensors present in the hypothalamus which triggers a cold-adaptive response[17]. According to some researcher, neonatal cold receptors primarily resides in the skin, however, warm receptor resides in hypothalamus. But both sensors are also believed to be integrated, as cold sensory response is inhibited by core sensor hyperthermia and vice versa.

### 2.6.2 Central Regulation

Hypothalamus is primarily responsible for integration of multiple skin temperature inputs. Under different environmental conditions, temperature of the skin can vary 8° to 10 °C, however, temperature of hypothalamus may vary ±0.5° C. However, the diseases like asphyxia, hypoxemia, and other central nervous system defects can have diurnal temperature fluctuations[18]. Normal infant (term infant) may regulate core temperature near 36.5 °C (97.7°F), whereas, premature usually respond by maintaining near 37.5°C (99.5°F) . The minute temperature deviations of even 0.5°C can triggered important thermoregulatory processes. Therefore, homeothermy of environmental temperature is important.

### 2.6.3 Efferent

Sympathetic nervous system plays the primary role in mediating the effector limb of the thermal response in neonates. Cutaneous arteriolar vasoconstriction that results in decreased flow of warmer blood from the infant's core to the cold periphery is the earliest neonatal response[19]. Moreover, decreased blood flow places an insulating fat layer in between the warmer core tissue compartment and the cooler skin surface of the full- term infant. Low birth weight babies have decreased fat content; therefore, they cannot effectively respond to environmental temperature changes. Vasoconstriction however is the primary response to temperature variations in neonates which is also present in the premature infants. Brown fat present in different areas of a newborn like axilla, mediastinum, perinephric region is highly enervated and has abundant mitochondria which are responsible for hydrolysis and re-esterification of triglycerides and oxidation of free fatty acids, this constitutes metabolic source of non-shivering thermogenesis. Therefore, brown fat is another sympathetic effector organ, as babies do not shiver to produce heat because the myelination of muscle fibers has not yet occurred. These reactions double the metabolic rate in full-term infants. As the preterm babies have decreased amount of brown fat, they cannot increase the metabolic rate to more than 25% even in the severe cold (Hull, 1966).

## 2.7 Historical Perspective – Infant Incubator

Infant incubator was first invented in 1870s by French obstetrician Ste´phane Tarnier, found a way to warm the premature infants who generally succumbed to hypothermia. He got inspired from chicken incubator which was displayed in the Paris Zoo[20]. The first incubator by Tarnier housed several infants (as inspired from chicken incubator) using hot water reservoir attached to an external heating source[21]. Later, he simplified the design to a single infant model using hot water bottles to warm the environment which were replaced after every 3 hours. Ventilation is based on simple convection, with air entering at the base and circulating upward and around the new borne.

Figure 2: Tarnier's Incubator Design - 1884

### 2.7.1 Invention of Closed Type Incubator

In 1883, German obstetrician Carl Crede float the idea of using closed type incubator rather than open design[22]. This resulted in drastic decrease in mortality of infants in the 1200 to 2000 grams range i.e. from 66% to 38%, almost half.

### 2.7.2 Alexandre Lion Model

In 1890, French physician Alexandre Lion developed a much more sophisticated incubator than that of Tarnier. It consists of a large metal apparatus, with a thermostat and an independent forced ventilation system[23]. This design was to compensate for less than optimal nursing or environment. But unfortunately, it was not a cheap solution and limit it's use in government hospitals only.

### 2.7.3 Back to Mother

The initial infant nurseries found to be disastrous as the infant were either brought late or already highly compromised due to other illnesses. This gave the general impression of reduce benefits of these devices. In 1900, Budin, well known French obstetrician, recognized as an international authority on the care of premature infants. His book Le Nourrisson ("The Journal of Perinatology 2000; 5:321–328 323 The Incubator and Discovery of the Premature Infant Baker Nursling") proposed upon breast-feeding and maternal involvement. His theory produced admirable statistics, but he shifted his focus to 2000 to 2500 grams range relatively mature infants while discarding deaths in the initial 48 hours. In 1902, Adolph Pinard, widely known French obstetrician, proposed the new theory and urged government shift its resources from treatment to prevention and proposed the theory 'Back to Mother' that working class women spending the last part of pregnancy in a municipal shelter were half as likely to deliver prematurely as compared to their working counterparts, and advocated maternity leave as the best strategy to assure a "strong and vigorous population" in the future[24]. Both centered their efforts not on technology but on efforts to educate and support the mother. Although the incubator was never abandoned, it retained a decidedly secondary role. The incubator further helped in reducing the premature infant mortality but the technology progressed slowly over the next 50 years. This invention later helped in shifting the responsibility of newly borne baby from mother to physician and by 2nd World War from obstetrician to pediatrician.

### 2.7.4 Concept of Special Care Baby Units (SCBUs)

After Second World War, concept of special-care baby units (SCBUs) evolved and established in many hospitals of Britain. At that time, Incubators were very expensive, so instead of incubator whole room was often kept warm. Strict nursing routines involved wearing masks, gowns, hand-washing and minimal babies handling were devised to control cross-infection between babies[25]. Parents at times allowed to watch babies through the windows of the unit. Frequent tiny feeding routine found best. Until the end of the 1950s, oxygen was given freely but it was learnt that high concentrations reached inside incubators can caused blindness in some babies. After that baby and environmental conditions in the incubator become a major area of research.


Figure 3: SCBU (Berlin Hospital) - 1989

### 2.7.5 St Thomas's Tube Invention - 1960

Rapid medical advances seen in 1960s especially in respiratory support. At that time, babies born under thirty-two weeks of age, often suffered neurological impairment. Herbert Barrie, considered as pioneer in advances in resuscitation of the newborn, published his paper and showed his concern on that using high pressures of oxygen could be damaging to newborn lungs. He proposed underwater safety valve in the oxygen circuit. Moreover, Barrie switched to plastic endotracheal tube instead of using rubber one as these had the potential to cause irritation to sensitive newborn tracheas. This Barrie's design, was later known as the 'St Thomas's tube'[26].

### 2.7.6 Concept of Neonatal Intensive Care Unit (NICU)

By the 1970s, concept of NICU evolved in the developed world and became part of hospitals. By the 1980s, more than 90% of births took place in hospital as special care of babies through technological monitoring and therapy became hospital-based. Now babies weighing less than 1.5 kg had survivability rate of almost 80% as compared to around 40% in the 1960s. In 1982, sub-specialty of neonatal medicine also came into being as now pediatricians in Britain could train and qualify in the said field. Now very small, premature, or congenitally ill babies are being treated in NICUs. Premature labour and prevention of the same still remains a mystifying problem. It is now advancement in the field of Neonatology and NICUs which have greatly increased the chances of survival of very low birth-weight neonates and very premature babies. Before NICUs era, infants having birth weight below 1400 grams rarely survived but now a days, neonates of 500 grams at 26 weeks have a fair chance of survival. The NICU now poses certain challenges as well as benefits. Challenges can be a continual light, a high noise level, mothers separation, minimum physical contact, painful procedures, and interference to breastfeed. NICU can be stressful for both parents and health care professionals as infants may survive, but still have the possibility of impairment to the brain, lungs or eyes.

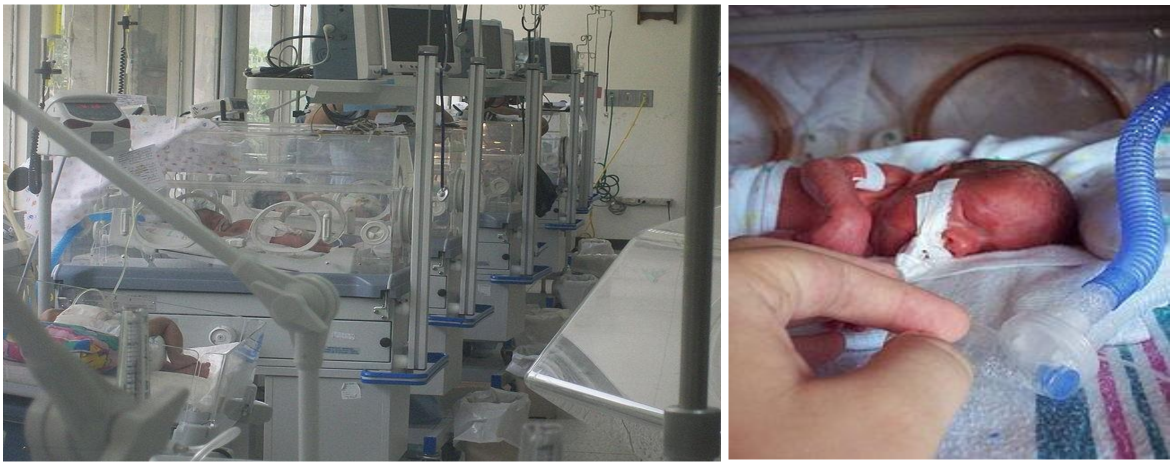

Figure 4: Neonatal Intensive-Care Unit in 2009

## 2.8 Latest Trends in Infant incubator

The infant incubator now a days are based on microprocessor to monitor and control the critical parameters like temperature, humidity and oxygen concentration. The accuracy and stability of these parameters are very high. The accuracy of temperature is around $\pm$ 0.5 °C and RH (Relative Humidity) is 5 to 10%. Number of safety features, alarms and protections are incorporated in the design to ensure safety of premature infants. Moreover, advance features like photo therapy unit (for treating jaundice), facility of IOT (Internet of Things), ECG and vital signs monitoring are also being provided[27]. The design also focuses on robustness and reliability of device including maintenance of uniform temperature, humidity and air flow to minimize heat loses of premature infant. A typical of incubator, now a days, equipped with following components / modules:-

**A.** Core Base Assembly.

**B.** Heating Compartment.

**C.** Humidifier Compartment.

**D.** Canopy.

**E.** Trolley.

**F.** Microprocessor based Electronic Interface

**G.** IOT (Internet of Things) Module for displaying Temperature & Humidity Graphs and Event Monitoring.

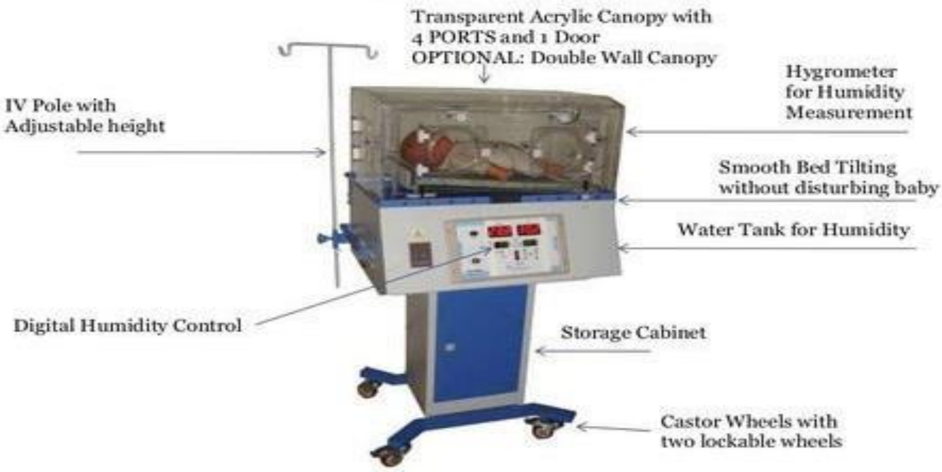


Figure 5 - A Typical Infant Incubator

### 2.9 Summary

This chapter focuses on the importance of thermal regulations in extremely premature and premature infant. Different physical phenomena involved in heat loss in infants are also elaborated. Moreover, the physiology of cold response is also covered in detail so to fully understand the thermal responses of infant. Infant Incubator is also analyzed from historical perspective alongwith latest trends being followed.

# 3 Research Methodology

## 3.1 Work Flow

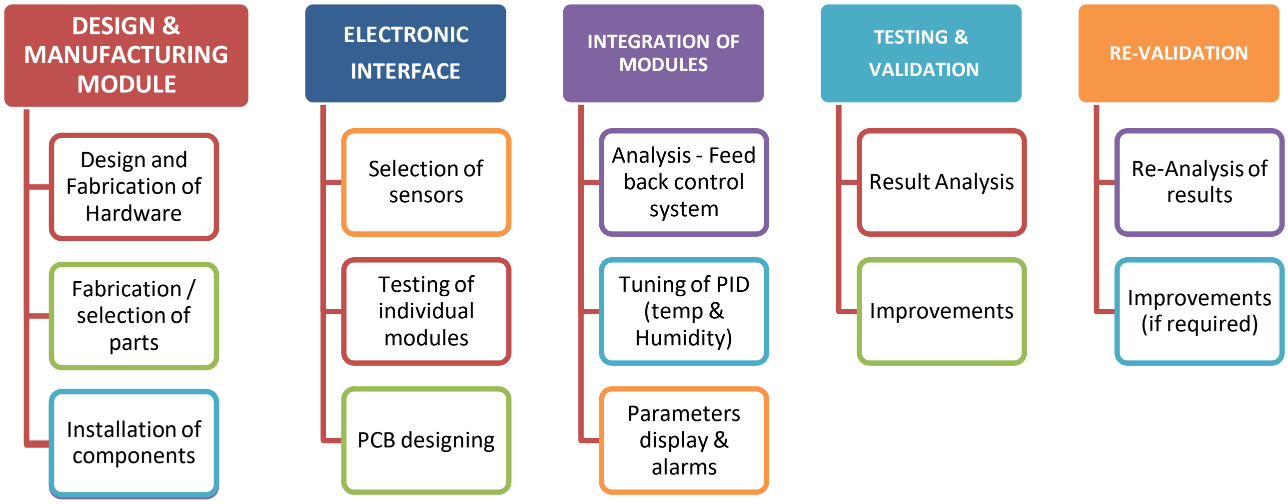


Figure 6: Work Flow

## 3.2 Designing & Manufacturing of Modules

Designing and manufacturing of device is based on predicate device i.e. Infant Incubator IP-100 Care Vision (CE Marked). Project is under taken in two phases. Phase one deals with fabrication of mechanical parts and installation of these components while phase two deals with designing and development of electronic interfaces. Following modules were designed / fabricated:-

- **A.** Casting of Core Base Assembly.
- **B.** Fabrication of Fan and Heater Module.
- **C.** Fabrication of Canopy and Trolley.
- **D.** Fabrication of Humidifier Module.
- **E.** Designing and Fabrication of Electronic Interface.
- **F.** Circuit Design.
- **G.** IOT Module.

### 3.2.1 Casting of Core Base Assembly

The core base assembly is the most important part of the infant incubator which houses the fan, heater assembly and humidifier module. A robust core assembly, made of aluminum is sand casted using predicate device. It is powder coated which act as insulation layer to avoid any short circuiting.

Figure 7: Sand Casting of Core Assembly

### 3.2.2 Fabrication of Fan and Heater Module

An AC motor having 1600 RPM along with metallic vane type fan is selected for air flow in the infant incubator. Moreover, a dry heater element (220 V AC , 400 watt) is selected to warm the temperature of incubator. Both components are installed in fan and heater module.

Figure 8: Fan and Heater Assembly

### 3.2.3 Fabrication of Canopy and Trolley

The incubator is portable in nature. For this purpose, incubator is trolley mounted having 4 x lockable castor wheels. The canopy of incubator is made of acrylic which is biocompatible. The dimensions of canopy is 34”x16”x14.5” (LxWxH) having six access port for easy handling of infant.

Figure 9: Acrylic Canopy and Trolley

### 3.2.4 Fabrication of Humidifier Module

To produce desired RH (Relative Humidity) from 20% to 95%, a humidifier based on ultrasonic humidifier sensor is installed which is very efficient and have fast response as compared to conventional steam base humidifier. Water tank capacity of humidifier is 2 liters which is sufficient for 6 hours of continuous operation.

Figure 10: Humidifier Module

### 3.2.5 Electronic Interface

The infant incubator is microcontroller based system to monitor and control the critical parameters like temperature and humidity inside the chamber[28]. To ensure the exact monitoring and control of these parameters, reliability and stability of sensors are of utmost importance.

#### 3.2.5.1 Sensor Selection – Temperature Sensor (DS18B20)

In infant incubator, air temperature and baby skin temperature are usually measured to ensure proper thermal regulation of premature infant. Minute temperature difference can be critical for neonate. So, the sensor must be very reliable, accurate and stable. To address this issue, a high resolution (12 Bit), accurate digital sensor i.e. DS18B20 (one wire, programmable, high resolution) is chosen[29]. As the temperature of chamber is kept around 36.5 to 37.5 °C, therefore this sensor is ideal, having linear response in desired temperature ranges.

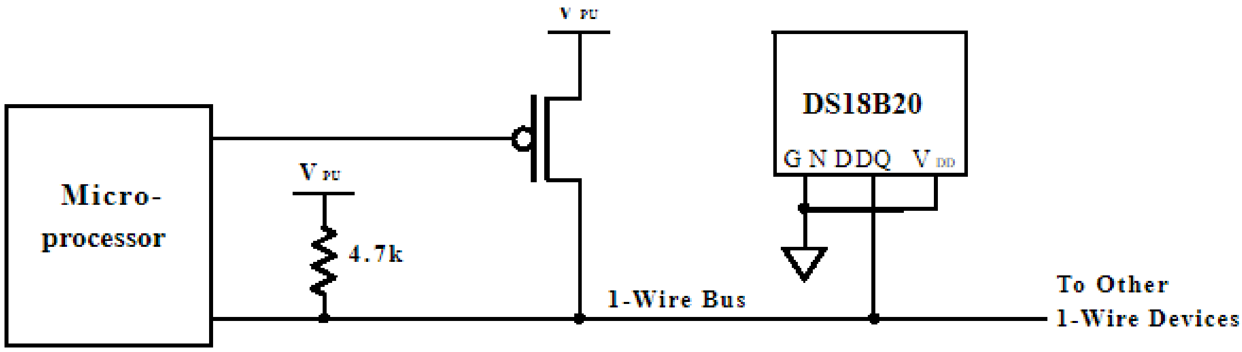


Figure 11: Typical Parasitic Configuration Circuit

##### 3.2.5.1.1 Temperature Sensor – Electrical Characteristics

The important characteristics of this programmable temperature sensor is also shown in the under mentioned table.

| Characteristic | DS18B20 |
|---|---|
| Type of Sensor | Digital |
| Measurements Range | -55° C to +125 °C |
| High Accuracy Temperature Range | -10 °C to +85 °C (accuracy ± 0.5%) |
| Operating Voltage | 3 ~ 5 Volts DC |
| Method / configuration | One wire Communication |
| Resolution (Programable) | 12 Bits maximum<br>(0.0625 °C increment at 12 Bits) |
| Conversion Time | 750 msec (for 12 bits) |

Table 1 – Electrical Characteristics of DS18B20

#### 3.2.5.1.2 Temperature Sensor – Performance Curve

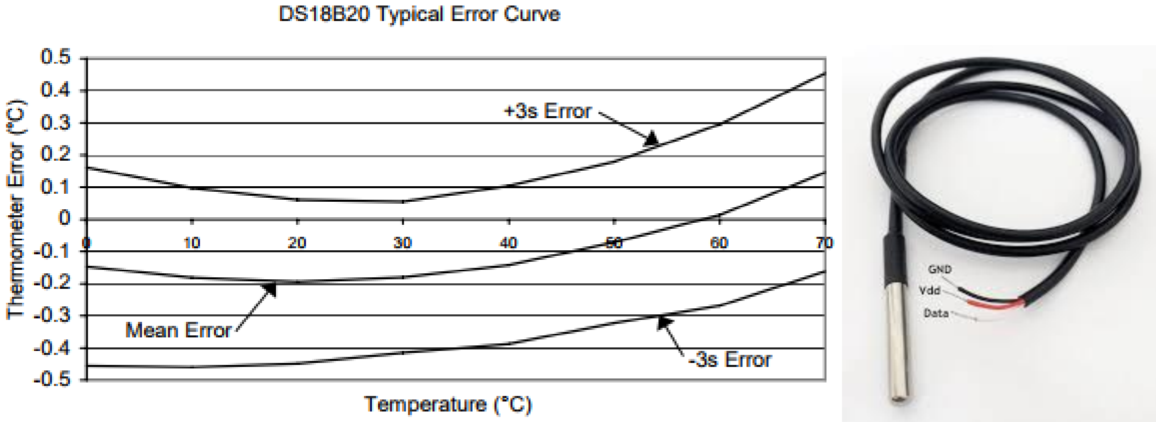


Figure 12: Typical Error Curve – DS18B20

### 3.2.5.2 Sensor Selection – Humidity Sensor (HIH 5031)

A very accurate, medical grade, low voltage, analog humidity sensor of Honeywell is used to measure the RH Humidity of infant incubator. This capacitive sensor is highly stable having near linear output voltage response. The sensor is perfect to be used in the desired temperature range. The RH Humidity can be measured by putting output voltage value of sensor (sensor RH) and present Temperature (T in °C) in following two equations.

**VOUT=(VSUPPLY)(0.00636(sensor RH) + 0.1515)**, typical at 25 °C ------**Equation I**

**True RH = (Sensor RH)/(1.0546 0.00216T)**, T in °C------- **Equation II**

#### 3.2.5.2.1 Humidity Sensor – Electrical Characteristics

| Characteristic | HIH-5131 |
|---|---|
| Type of Sensor | Analog (Capacitive type) |
| Operating Temperature Range | -40° C to +85 °C |
| Accuracy | ± 3% RH |
| Supply Voltage | 2.7 ~ 5.5 Volts DC |
| Hysteresis | ± 2% |
| Repeatability | ± 0.5 |
| Stability at 50% RH | ±1.2 %RH |

Table 2 – Electrical Characteristics of HIH 5131

### 3.2.5.2.2 Humidity Sensor – Operating Environment Response

This humidity sensor has very stable output response to operating temperature environment which makes it ideal for incubator monitoring.

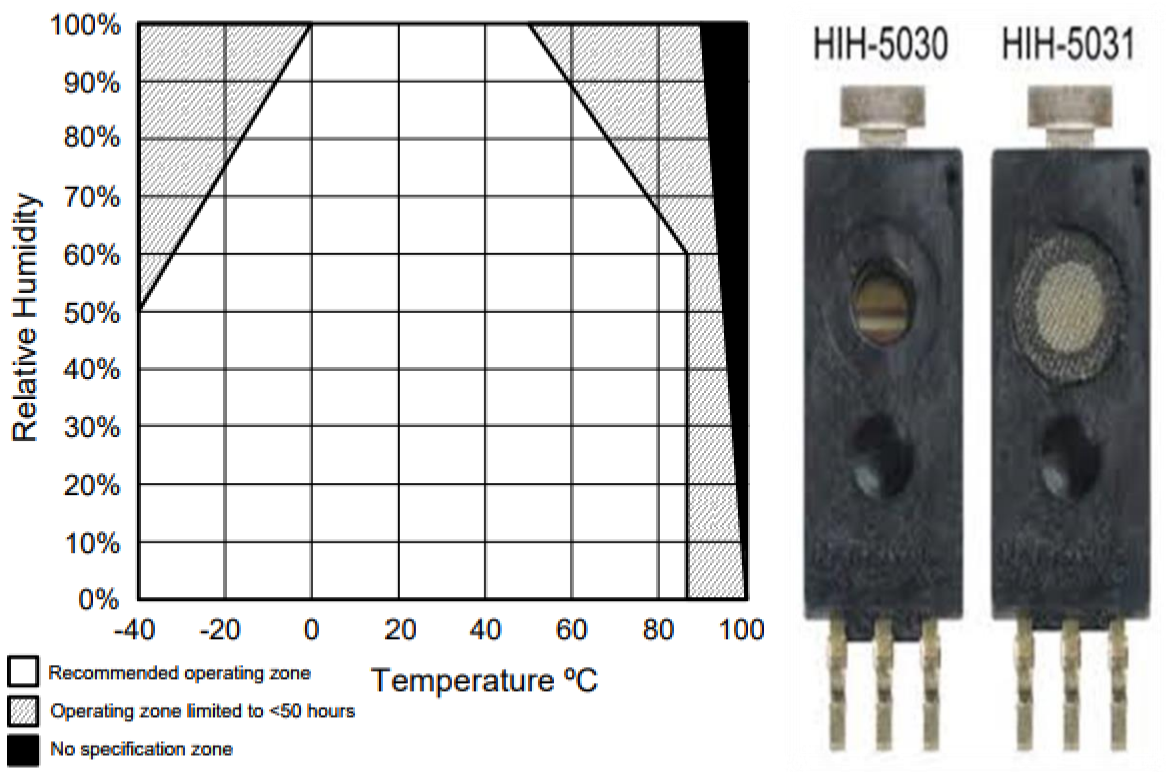


Figure 13: Humidity Sensor vs Operating Temperature

### 3.2.5.2.3 Humidity Sensor – Output Response and Typical Application

The voltage output response of sensor is linear and very stable.

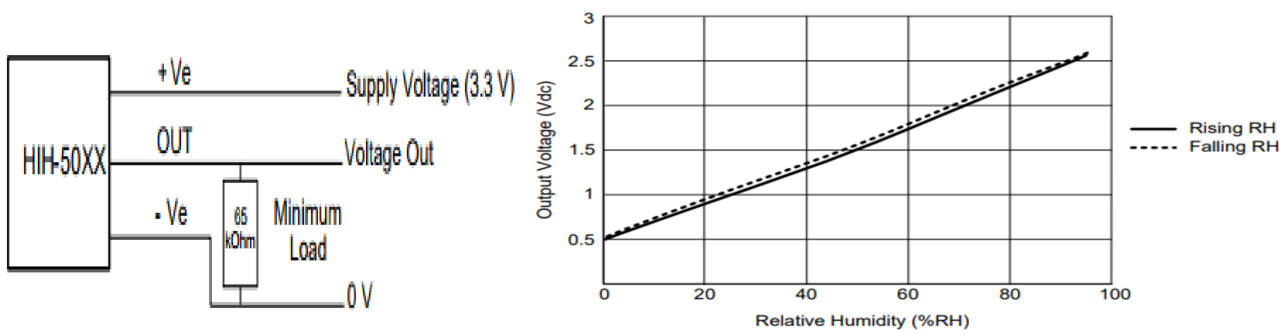


Figure 14: Response of Sensor – Voltage output vs Humidity

### 3.2.5.3 Mist Transducer – Ultrasonic Humidifier

In this project, an ultrasonic transducer is used to produce the mist. However, the conventional incubator use steam based heaters for the generation of humidity. The ultrasonic mist maker used in this project uses water to make mist. The transducer fully immersed in water oscillate at very high frequency (piezo ceramic disc resonates) and converts into high frequency mechanical vibrations. A momentary vacuum is produced on negative moment of piezo disc as water cannot follow the high frequency of transducer. The positive vibration of piezo disc creates high pressure waves that forces the cavitated water into very fine mist which is easily absorbable into air.

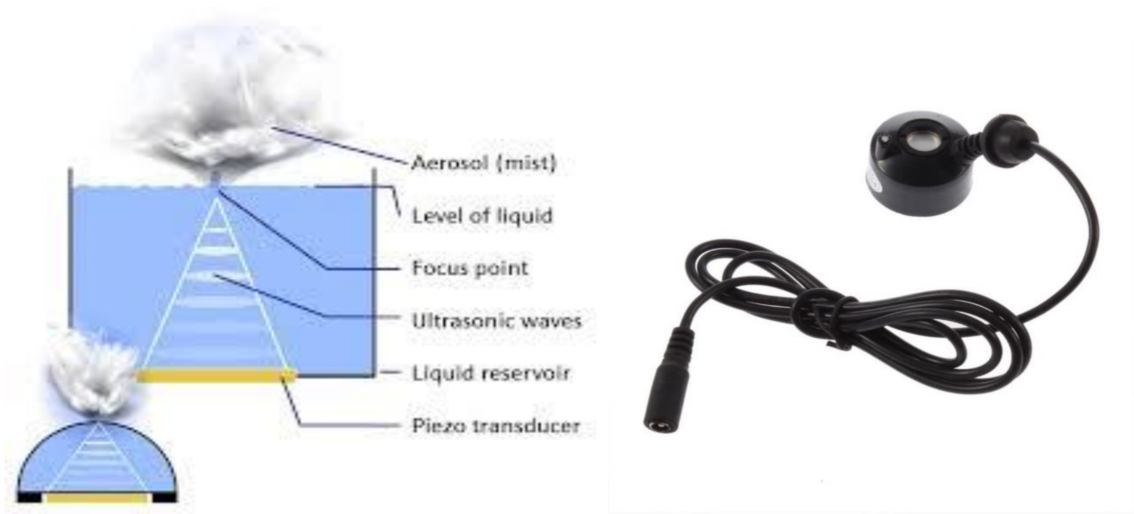


Figure 15: Ultrasonic Transducer

#### 3.2.5.3.1 Ultrasonic Humidifier – Electrical Characteristics

| Characteristic | Ultrasonic Transducer |
|---|---|
| Type of Sensor | Ultrasonic |
| Operating Temperature Range | 0 to +75 °C |
| Working hours | ≥ 5000h |
| Supply Voltage | 24 Volts DC |
| Resonant Frequency | 1.7MHz±0.05MHz |
| Resonant impedance | ≤3Ω |
| Water Consumption | 300 ml / hour |

Table 3 – Electrical Characteristics of Mist Sensor

### 3.2.5.4 Float Sensor

Float sensor is used to monitor the water level in humidifier module. When water level falls below 60%, the float valve operates and start giving indication of low water. The sensor is connected with Arduino Mega for feedback of water level in humidifier water tank.

Figure 16: Float Sensor

### 3.2.5.5 Front End Electronic Interface – Display of Parameters

The Front end electronic interface is kept simple and user friendly. The front end consists of 3 types of Seven Segment display for display of following:-

A. Display of Air Temperature in °C.

B. Display of Baby Skin Temperature °C.

C. RH Humidity (% RH).


Figure 17: Display of Air, Baby Skin Temperature & Humidity

#### 3.2.5.5.1 Front End Electronic Interface – Menu Selection

The front interface has main menu for which three different modes can be selected using desired push buttons. The appropriate push button can be used to select the desired mode i.e. Air Temperature, Baby Skin Temperature mode and Humidity Mode. After selecting the mode, the desired values of temperature and humidity can be set. This incubator can control and maintain the temperature in either ‘Air Temperature Mode’ or using ‘Baby Skin Temperature Mode’.

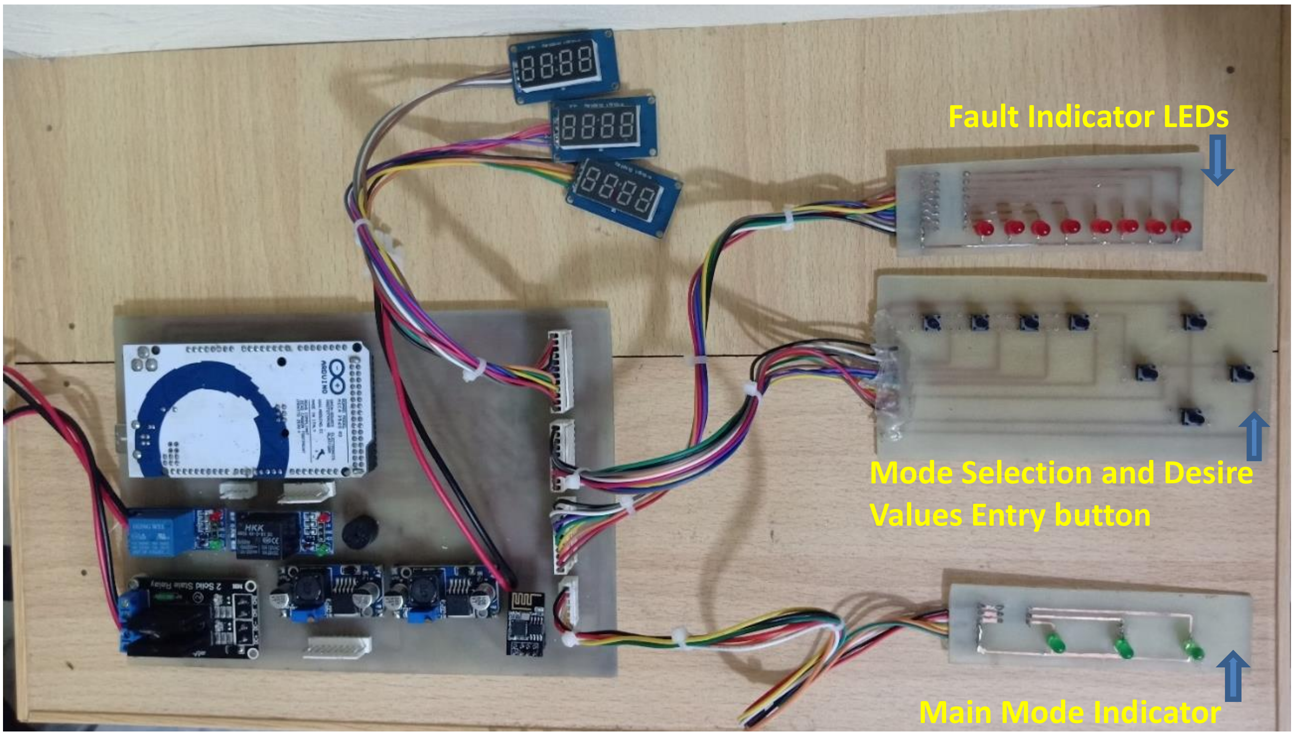


Figure 18: Front End PCBs

#### 3.2.5.5.2 Front End Electronic Interface – Protection and Alarm Indicators

Protections and alarms are also incorporated in design to ensure patient safety. In case of any issue, buzzer will be activated and give high frequency as well as low frequency beeps depending on priority of alarms  The details of the same is as under:-

- **A.** Air Temperature Sensor Failure (High Priority)
- **B.** Skin Temperature Sensor Failure (High Priority)
- **C.** Humidity Sensor Failure (High Priority)
- **D.** Humidity low / high (Low Priority)
- **E.** Low Air Temperature (High Priority)
- **F.** High Air Temperature (High Priority)
- **G.** Low Water Level (High Priority)
- **H.** Low / High Skin Temperature (High Priority)

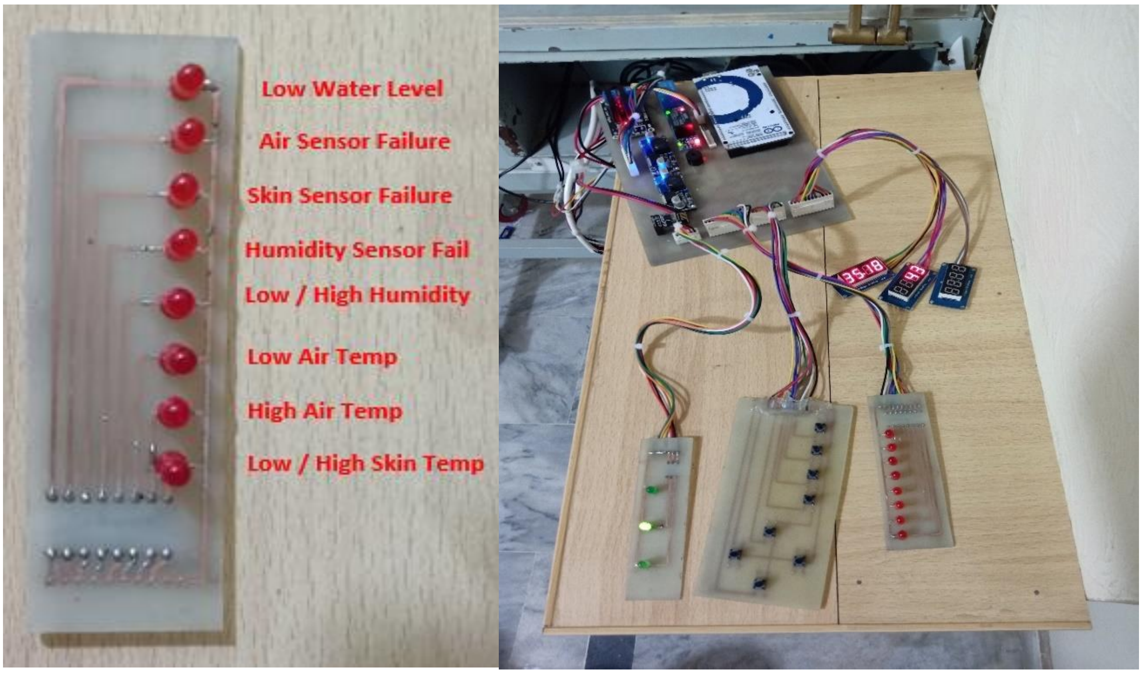


Figure 19: Fault / Alarm Indicator PCB

#### 3.2.5.5.3 Electronic Circuit - Integration

Arduino Mega 2560 is the main controller used to control and monitor the critical parameters. The AC Fan Motor and Heater Element (220 VAC, 400 Watt), both are connected with Arduino using SSR (Solid State Relays). Fan is permanently ON while Heater Element is switch ON / OFF as per the feedback as well as proportional to error of PID controller. Similarly, the Mist transducer is also being controlled by the Arduino Mega using PID controller which is also switch ON / OFF as per the feedback. Both Heater Element and Mist transducer are controlled independently using separate PID controllers. The main components interface with Arduino are as under:-

**A.** Fan Motor (220V AC) interfaced with Arduino Mega using 5V DC to 220 VAC SSR.

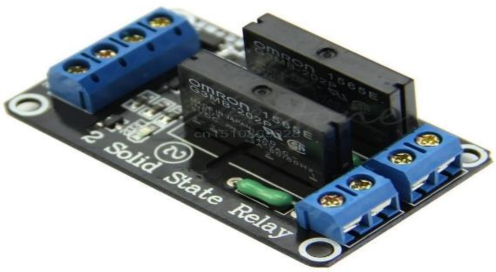


Figure 20: Solid State Relay - 5VDC to AC

**B.** Heater Element (220 VAC, 400 Watt) also interfaced using SSR.

**C.** 2 x Temperature Sensors (Air temperature & Baby Skin temperature), one humidity sensor and 1 x float sensor.

**D.** Interfacing Ultrasonic Mist transducer.

**E.** 3 x Seven segment displays for displaying temperatures and humidity.

**F.** Mode selection and alarm / protection PCBs.

**G.** Interfacing with Wifi Chip ESP8266 (IOT Module)

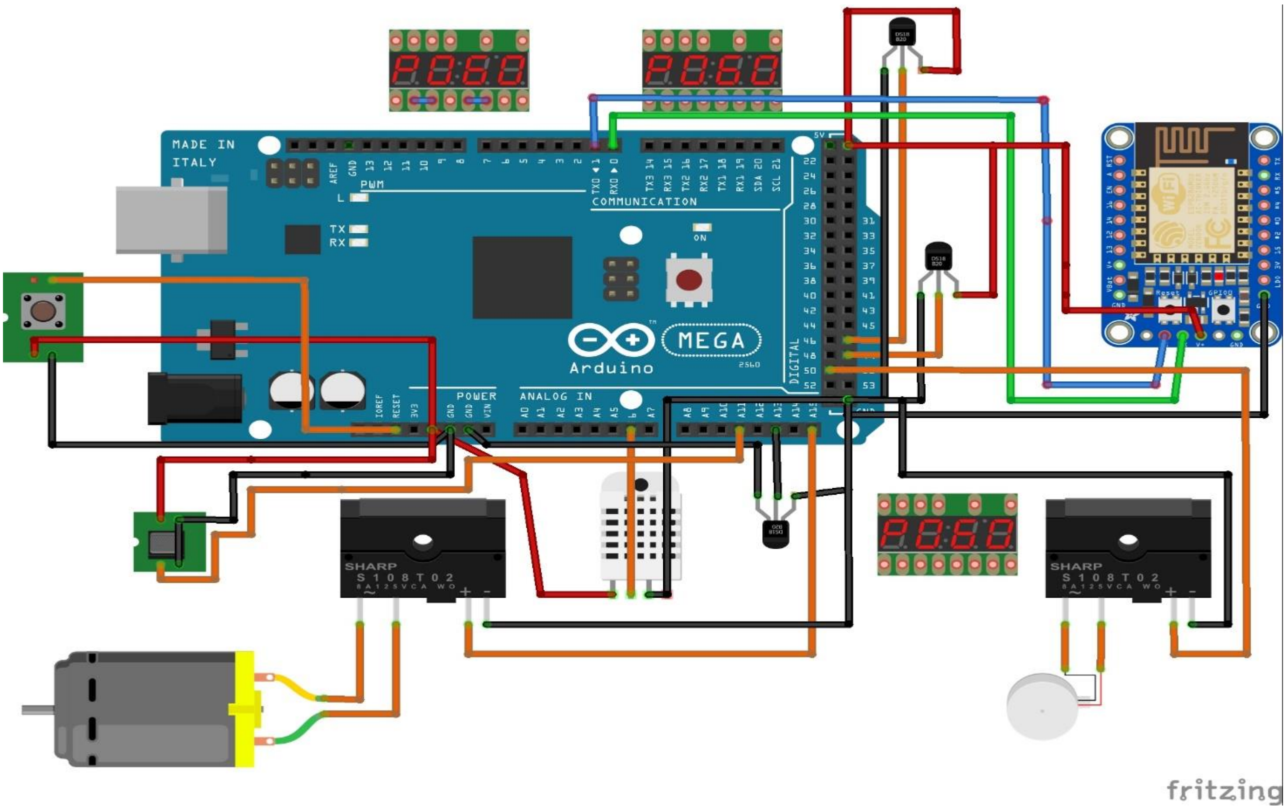


Figure 21: Circuit Diagram

#### 3.2.5.5.4 Implementation of PID Controllers

The temperature and humidity are monitored and controlled independently as per desired ranges (set points) using PID controller[30]. To achieve the precise control, PID function is implemented in Arduino. Algorithm used to control / maintain the temperature is based on switching the heater element (ON / OFF) according to feedback (output error). In each 5 sec, the maximum ON time of heater element is kept 3.5 seconds (in case of maximum error) and minimum OFF time of heater is 1.5 seconds. The temperature is monitored after every sec. Output error is estimated using PID and accordingly ON/OFF timings of heater is controlled. Similarly, ultrasonic transducer is also switch

ON/OFF as per feedback (output error). The main governing equation of PID is as under

$$u = \underbrace{K_p e}_{\text{Proportional Term}} + \underbrace{K_i \int_0^t e\,dt}_{\text{Integral Term}} + \underbrace{K_d \frac{d}{dt} e}_{\text{Differential Term}}$$

The PID is also fine tuned and observed values are Kp = 800, ki = 20 and kd = 120. After fine tuning, the response of temperature and humidity was found fast, stable and accurate (discussed in Result section). Detail code of PID is also attached as Annexure ‘A’ for reference.

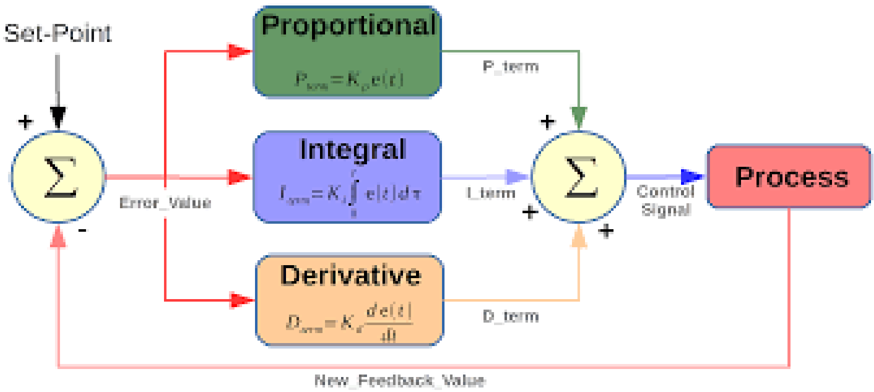


Figure 22: PID Block Diagram

### 3.2.6 IOT(Internet of Things)

The temperature and humidity parameters are also displayed remotely using IOT. For this purpose, the Wifi chip ESP 8266 is interfaced with Arduino Mega. The Tx and Rx pins of Arduino is interfaced with Rx and Tx pin of ESP 8266. For real time monitoring of temperature ((Air temperature, Baby Skin temperature (although not tested)) and humidity, the open IOT platform www.thingSpeak.com was utilized. The data is updated after every 15 seconds. The graphs plotted in real time are discussed in Result Section. Followings are the three objectives to be obtained[31]:

**A.** Data Transmission

**B.** Data Recording

**C.** Remote Data Display

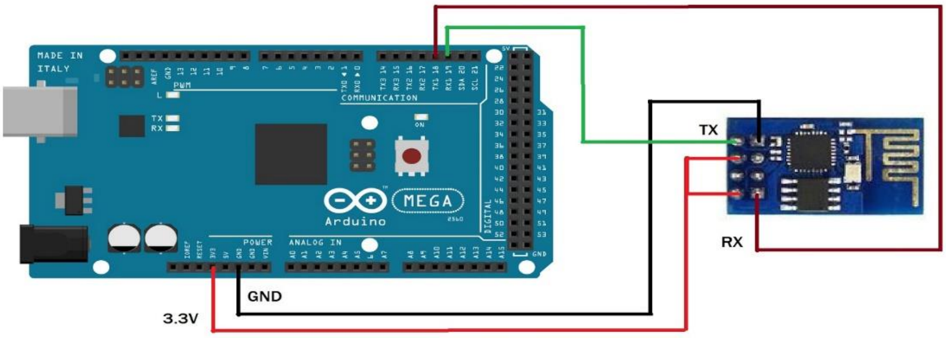


Figure 23: Typical Application Circuit – ESP8266 with Arduino Mega

### 3.2.7 Integration and Working of Infant Incubator

This incubator is designed on forced convection system in which filtered air is allowed inside incubator[32]. Forced convection is achieved as vane type fan motor is used which creates a suction effect. To ensure a filtered air, a bacteria filter is installed at initial pathway which ensure a clean air. The filtered air passes through heater and becomes warm. On the way, it passes through ultrasonic humidifier module which generates a very fine mist which is easily absorbed in the air. The AC Fan motor is of 1600 RPM which is permanent ON in this design and causing air flow of 10 cm / sec (not measured) as it was claimed in predicate device. The speed of Fan motor as well as vane are kept similar as per original design.

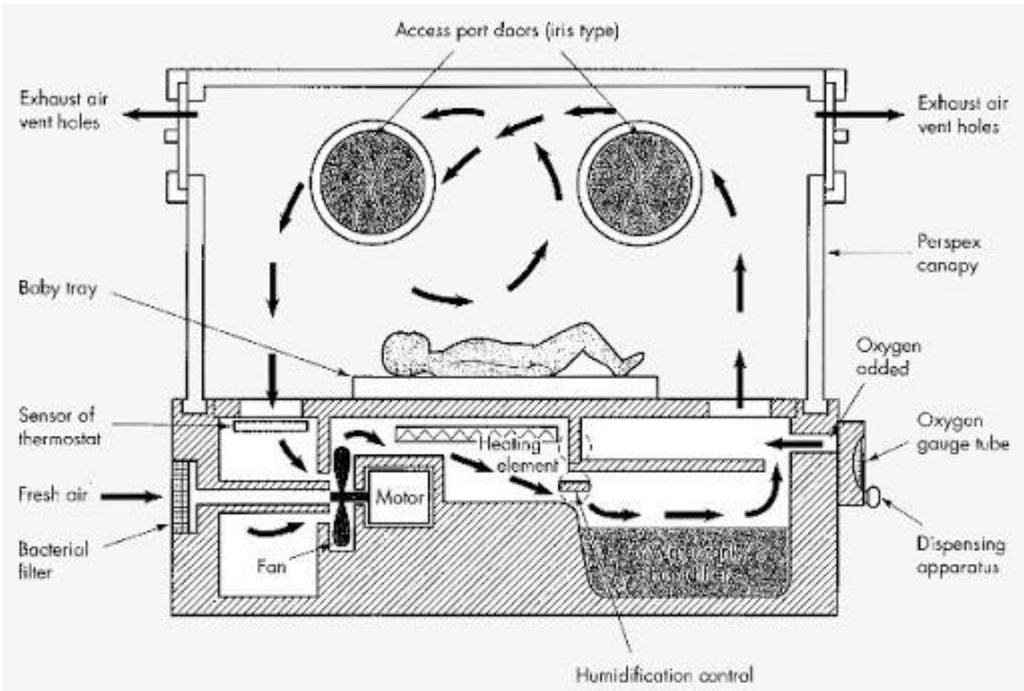


Figure 24: Force Convection based Infant Incubator

### 3.2.6 Flow Chart – Software Implementation

Flow chart diagram of the software implemented is elaborated as under:-

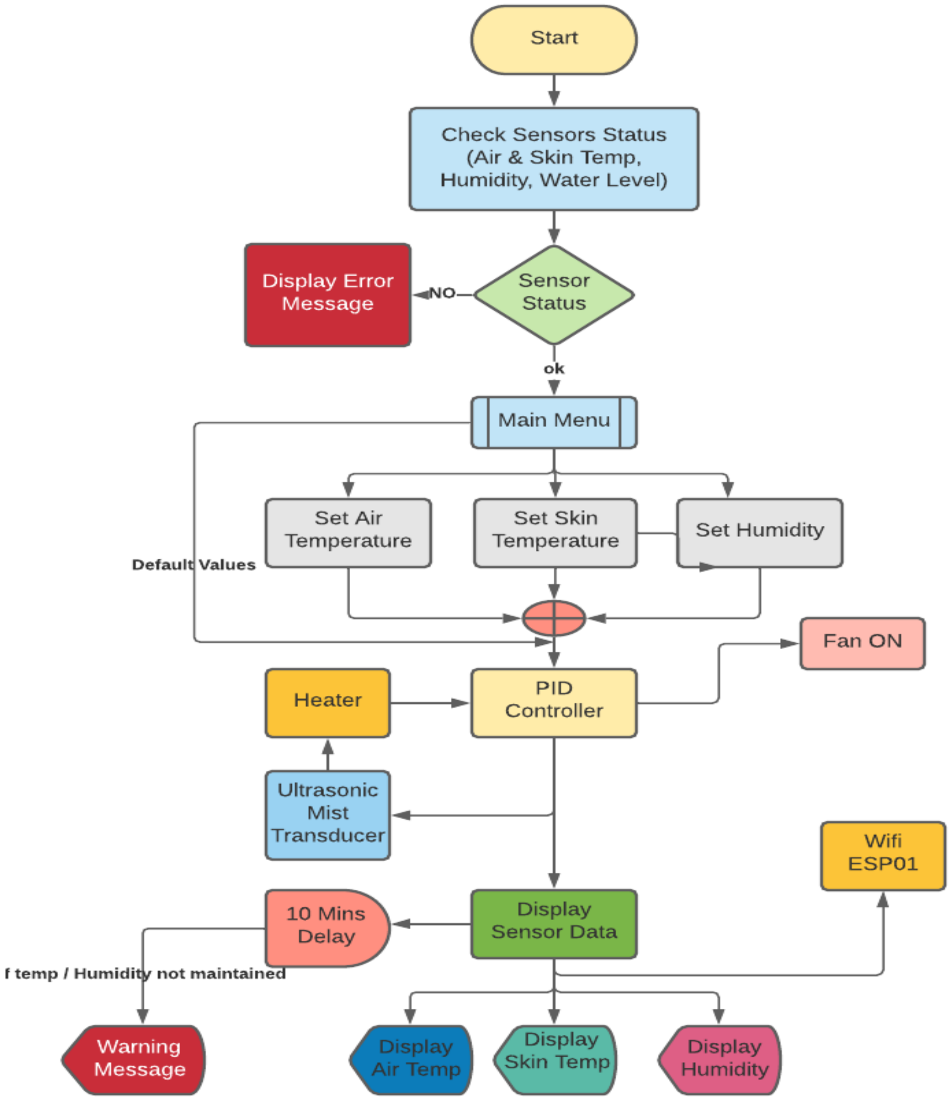


Figure 25: Flow Chart

### 3.3 Summary

The main focus of this chapter is on the designing and fabricating a robust, reliable and efficient infant incubator locally. The chapter discuss the fabrication / manufacturing of incubator in detail. Moreover, electronic interface is also discussed in detail which includes different types of sensors and components used in circuit design to make it reliable and efficient. The prototype is a complete product and project can be taken at commercial / industrial scale to develop reliable and efficient infant incubator at much low cost as compared to those available in market. This will help in better health facilities in remote areas with limited resources and will increase life expectancy of premature infants.

# 4 Results & Discussion

Once the device is developed and fully integrated , incubator is required to be thoroughly tested to analyze and validate its effectiveness. The accuracy and stability of sensors are very important and same needs to be analyzed. For this, set points of air temperature and humidity are defined and response, accuracy and stability are noted. The incubator response is also tested for high humidity value i.e. RH 80% to analyze the efficiency of ultrasonic mist transducer. Moreover, during testing phase, PID controllers are also fine-tuned to achieve best possible response and stability of these critical parameters. The incubator is tested against following parameters:-

- **A.** Air Temperature and baby skin temperature accuracy and stability.
- **B.** Humidity accuracy and stability.
- **C.** Humidity response vs time.
- **D.** Performance comparison of developed incubator with latest state of the art incubator

### 4.1 Monitoring of Air and Baby Skin Temperature

Baby skin temperature mode for monitoring the fever of infant and controlling thermal regulations against set temperature is also available. However, the same could not be tested on the subject due to obvious reasons i.e. patient safety issues being a prototype. However, the accuracy and stability of temperature environment inside infant incubator has been thoroughly analyzed.

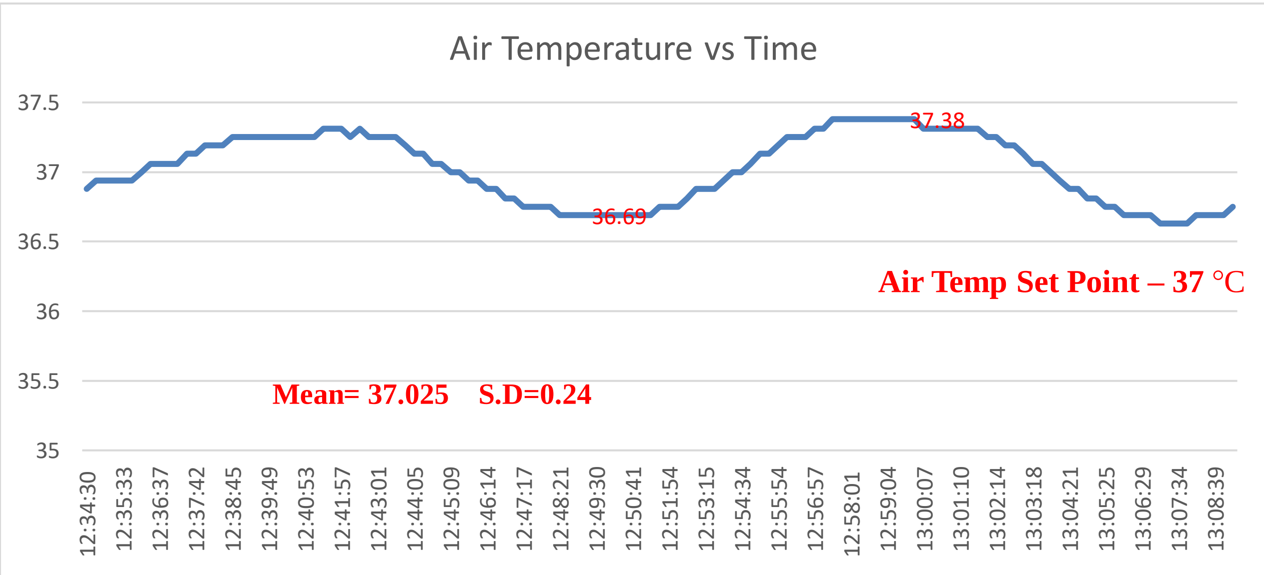


Figure 26: Air Temperature Response vs Time

### 4.1.1 Analysis – Air Temperature

The air temperature of infant incubator is set at 37°C. The infant incubator maintains the temperature fairly with minimum value of 36.69 °C and maximum value of 37.38°C having accuracy of ± 0.4°C. Moreover, Mean and Standard Deviation also calculated. The value observed are as under:-

- **H. Observed Mean value = 37.025**
- **I. Standard Deviation = 0.245**

### 4.1.2 Air Temperature Initial Response

The initial response of incubator is also analyzed. In the initial phase, the PID error is maximum. So the PID controller make the heater element ON for maximum time. It has been observed that infant incubator takes 15 minutes 30 seconds to achieve the desired temperature i.e. 37°C. It means that this incubator requires 15 to 20 minutes preparation time to achieve the set temperature (37°C) when placed at room temperature.

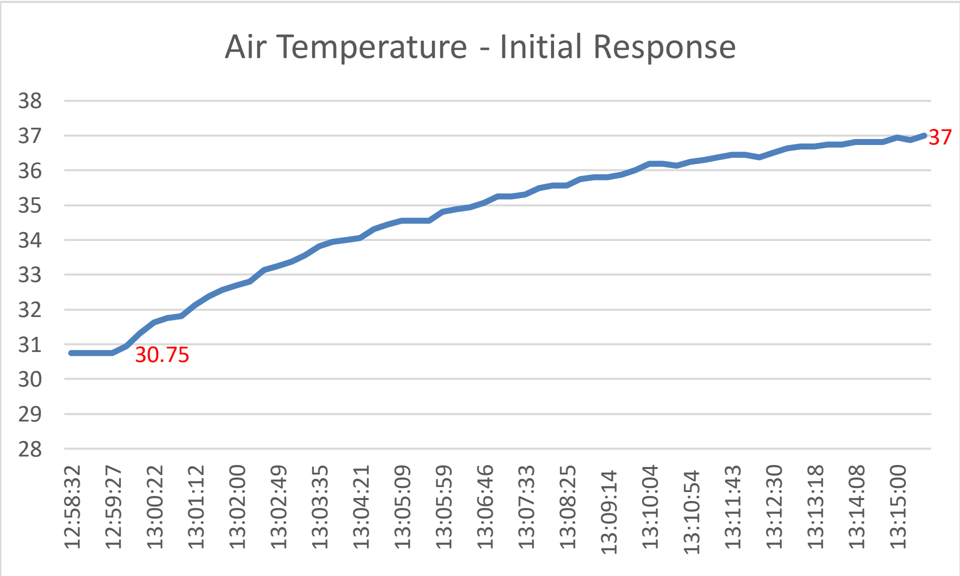


Figure 27: Air Temperature Initial Response

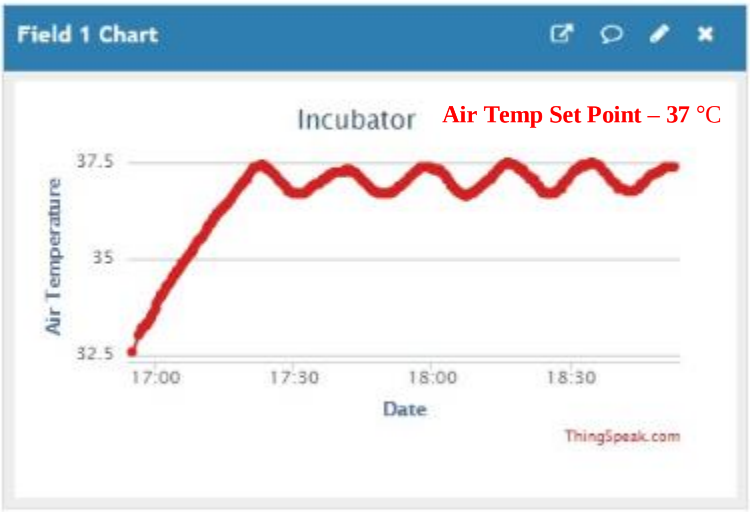


Figure 28: IOT Graph – Air Temperature IOT Graph

### 4.2 Humidity Response – Infant Incubator

The ultrasonic mist transducer is used to maintain the humidity inside infant incubator against the conventional steam base heater. The ultrasonic humidifier is found to be very efficient as well stable even in case high humidity is set. The response of humidity is as under:-

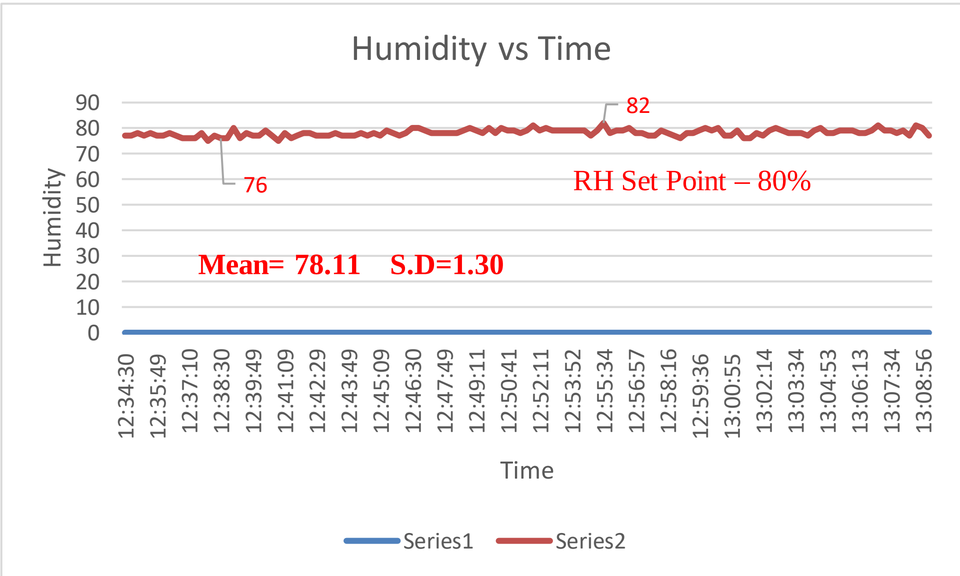


Figure 29: Humidity vs Time Graph

#### 4.2.1 Analysis of Humidity Response

The humidity response of incubator is also analyzed in detail and found fairly stable. The maximum value of RH is 82% and minimum value is found around 76%. The mean and standard deviation is also calculated. Detail is as under:-

A. Mean value = **78.12%**
B. Standard Deviation = **1.30**

### 4.2.2 Initial Response - Humidity

The initial response of ultrasonic humidifier is also analyzed and found very fast and efficient. It is observed that the ultrasonic humidifier achieved the 70% RH from initial value of 36% RH around 3 minutes. It  The graph of initial response is as under:-

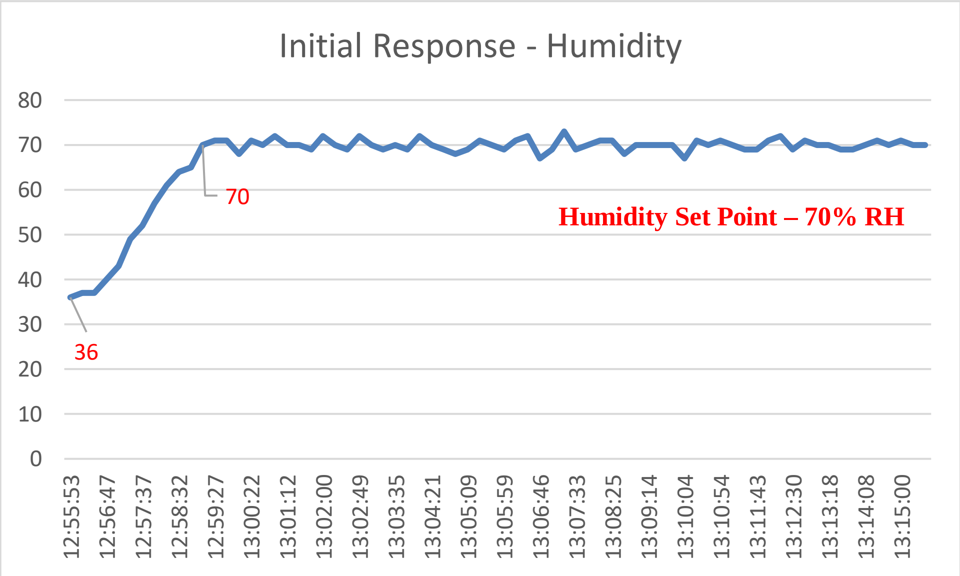


Figure 30: Initial Response - Humidity

### 4.2.3 Temperature – Humidity Response

The overall response (temperature and humidity) is also analyzed in detail. The humidity values are changed from 80%RH to 70%RH and its effect on temperature is also analyzed and found stable as shown in graph below:-

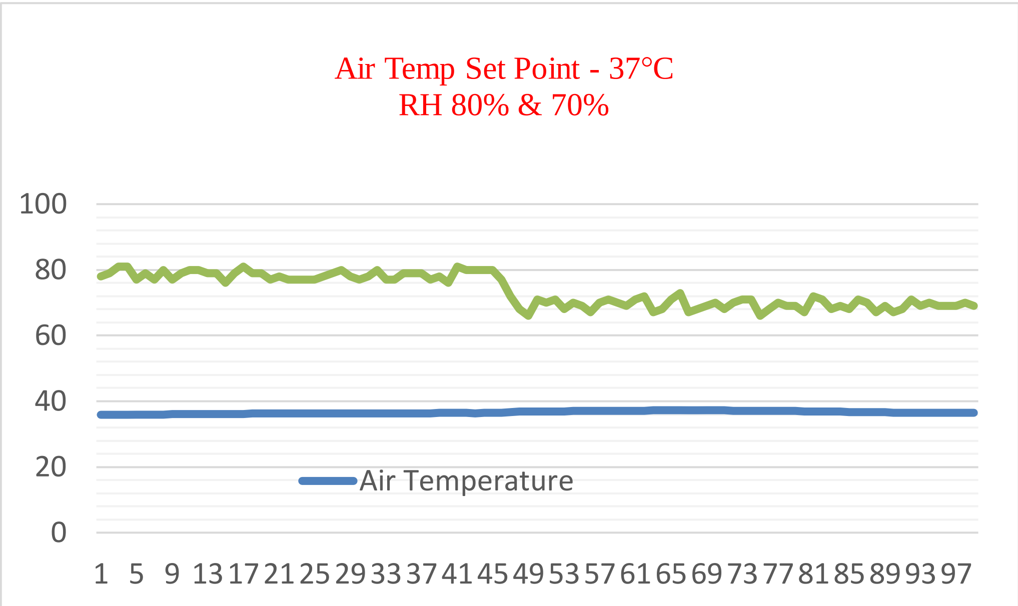


Figure 31: Air Temperature vs RH (80% & 70%)

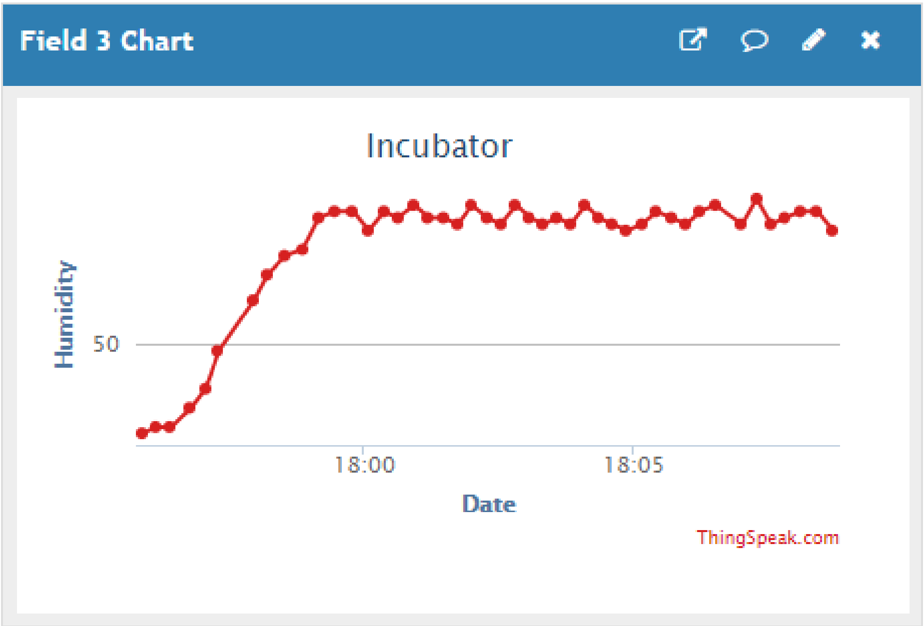


Figure 32: Humidity Response – IOT Graph

## 4.3 Discussions

The efficiency of developed incubator is also analyzed and compared with incubator study already conducted by Enilson J. L. Costa, Brazil and it was observed that S.D of temperature and RH (Relative Humidity) was 1.11°C and 2.99% which was based on passive humidity control system whereas the S.D values (temperature and RH) of this incubator is 0.24°C and 1.30% which is much superior[33].

In another study related temperature and humidity stability in infant incubator conducted by W.Widhiada, Indonesia claimed that by using Fuzzy logic control system, settling time for temperature (from 30°C to 35°C )and humidity (from RH 78.5% to RH 68%) is 215 seconds and 330 seconds respectively. Whereas in this project, settling time of humidity is much faster based on active system as it is less than a minute (from RH 80% to RH 70%) however settling time of temperature is around 500 sec[34].

In addition to above, the performance parameters especially temperature and humidity parameters of the developed incubator is also compared with commercial incubator i.e. BT-500, Made in France. These performance parameters are comparable to each other. The detail of the same is as under:-

| Serial No | Parameter | Commercial Incubator BT-500 (CE Marked, made in France) | Developed Incubator |
|---|---|---|---|
| A | Air Temperature Control Range | 23.0℃ ~ 37.0℃ ± 0.3 ℃ | 23.0℃ ~ 38.0℃ ± 0.4 ℃ |
| B | Skin Temperature Control Range | 35.0℃ ~ 37.0℃ ± 0.3 ℃ | 35.0℃ ~ 38.0℃ ± 0.4 ℃ |
| C | Humidity Control range | 40 ~ 95% ± 5 % RH | 40 ~ 95% ± 4 % RH |
| D | Humidity Measurement Range | 15 ~ 99% ± 5 % RH | 15 ~ 99% ± 4 % RH |

Table 4 – Comparison with Commercial Incubator

## 4.4 Summary

The chapter elaborates the results of critical parameters of infant incubator i.e. response and stability of temperature and humidity achieved inside the chamber. Moreover, performance parameters of developed incubator are also compared with different studies as well as with commercial incubator.

# 5 Conclusion and Future Works

The device design is cost effective solution which is not only robust but reliable as well. The equipment can be given to rural as well as remote areas with limited medical facilities.

## 5.1 Conclusion

The project deals with life saving medical equipment and designed keeping in mind the medical conditions available in rural / remote areas. This Equipment is a very robust, efficient, user friendly and can be effectively used by operators in a small health care facilities. It will help in enhancing life expectancy of premature infants at remote place with limited facilities. All components are available locally and can be easily replaced in case of any failure. Fabrication of core base assembly and canopy can easily be under taken locally. The chamber size is as per international standard and can sufficiently accommodate the neonates and premature babies. Electronic portion of machine is in modular form and can easily isolated to ensure patient safety. This incubator is robust, efficient and low cost solution and its performance parameters are comparable to commercially available incubator.

## 5.2 Limitations

The device is also having some limitations. The same are enumerated as under:-

A. The response of 400 Watt heater element is a bit slow but otherwise stable.

B. Baby Skin Temperature control mode is although available but could not be tested due to safety reasons.

C. The project is focused on controlling temperature and humidity. However, other parameters like oxygen concentration measurement inside the chamber not monitored.

## 5.3 Future Works

This study will help in further research and will be helpful to make infant incubator well equipped with different kind of sensors for vital signs monitoring of premature babies. Future work in following areas are recommended:

**A.** Incorporation of SPO2 sensor to measure oxygen concentration of premature infants.
**B.** The incubator can be made transportable by modifying the canopy and trolley.
**C.** Installation of isolation transformer and patient safety related aspects i.e. leakage current etc can be taken care off to make it more safe for use.
**D.** IOT platform can be extended to incorporate event monitoring,

Annexure A

# Software Code

## PID Controller

```
#include <OneWire.h>
#include <Arduino_FreeRTOS.h>
#include <Arduino.h>
#include <TM1637Display.h>
TaskHandle_t taskSensorHandler;
TaskHandle_t taskErrorHandler;
TaskHandle_t taskPIDHandler;
TaskHandle_t taskDisplayHandler;
TaskHandle_t taskWiFiHandler;

//Temperature Parameters
OneWire  AirTemp_object(7);
OneWire  SkinTemp_object(8);
float SkinTemp = 0;
float AirTemp = 0;
boolean SkinStatus = true;
boolean AirStatus = true;
double SetAirTemp = 28;
double SetSkinTemp = 28;
boolean T_MarginError = false;
boolean Air_Skin = true;  // true for Air mode False for Skin mode

//Humidity Parameters
int HumidityPin = A0;
double HumidityValue = 0;
boolean StatusHumidity = false;
double SetHumidity = 50;
boolean H_MarginError = false;
byte newSetHum = 0;
float newSetAirTemp = 0;
float newSetSkinTemp = 0;
boolean setStatus = false;
boolean humBtnStatus = false;
boolean AirBtnStatus = false;
boolean SkinBtnStatus = false;
boolean muteStatus = false;
byte enterBtn = 34;
```

```
byte upBtn = 35;
byte downBtn = 36;
byte setBtn = 37;
byte humBtn = 38;
byte airBtn = 39;
byte skinBtn = 40;
byte muteBtn = 41;
long manuPeriod = 0;
byte Fan  = 11;
int manuInterval = 10000;
long WarningTime = 0;
long BuzzerTime = 0;
byte counter = 0;
boolean toggleStatus = false;
long toggleTime = 0;

///////////////////
int countTrueCommand;
int countTimeCommand;
boolean found = false;

void setup() {

 xTaskCreate(GetSensor, "Sensor", 128, NULL, 0, &taskSensorHandler);
 xTaskCreate(Error, "Errorhandling", 128, NULL, 0, &taskErrorHandler);
 xTaskCreate(PIDController, "PIDhandling", 256, NULL, 0, &taskPIDHandler);
 xTaskCreate(DisplayControl, "Displayhandling", 128, NULL, 0, &taskDisplayHandler);
 xTaskCreate(WiFiControl, "WiFihandling", 1023, NULL, 0, &taskWiFiHandler);
 Serial.begin(9600);
 pinMode(enterBtn, INPUT);
 pinMode(upBtn, INPUT);
 pinMode(downBtn, INPUT);
 pinMode(setBtn, INPUT);
 pinMode(humBtn, INPUT);
 pinMode(airBtn, INPUT);
 pinMode(skinBtn, INPUT);
 pinMode(muteBtn, INPUT);
 pinMode(Fan,OUTPUT);
 digitalWrite(Fan,LOW);
 Serial.println("Starting");
 Serial1.begin(9600);
 }
```

```
void loop() {
bool setButton = digitalRead(setBtn);
if (!setButton) {
setStatus = true;
newSetHum = SetHumidity;
newSetAirTemp = SetAirTemp;
newSetSkinTemp = SetSkinTemp;
manuPeriod  = millis();
 }
 if (millis() - manuPeriod > manuInterval && setStatus) {
 setStatus = false;
  humBtnStatus = false;
 AirBtnStatus = false;
 SkinBtnStatus = false;
 manuPeriod  = 0;
 }

 if (setStatus) {
 bool h_btn = digitalRead(humBtn);
 bool a_btn = digitalRead(airBtn);
 bool s_btn = digitalRead(skinBtn);

 if (!h_btn) {
 humBtnStatus = true;
 AirBtnStatus = false;
 SkinBtnStatus = false;
 manuPeriod  = millis();
  }
 else if (!a_btn) {
 humBtnStatus = false;
 AirBtnStatus = true;
 SkinBtnStatus = false;
 manuPeriod  = millis();
   }
 else if (!s_btn) {
 humBtnStatus = false;
 AirBtnStatus = false;
 SkinBtnStatus = true;
 manuPeriod  = millis();
   }
   }
```

```
bool mute = digitalRead(muteBtn);
if (!mute){muteStatus = true; BuzzerTime=millis();}
if (millis()-WarningTime > 60000 && !H_MarginError)
 {
counter += 1;
WarningTime = millis();
if (counter > 9){
H_MarginError = true;
T_MarginError = true;
counter = 9;
    }
   }
if (millis() - BuzzerTime>120000 && muteStatus){
muteStatus = false;
BuzzerTime = millis();
if (millis() - toggleTime> 10000){
if (toggleStatus){toggleStatus = false;}
else if (!toggleStatus){toggleStatus = true;}
toggleTime = millis();      }
```

## Display Control Module

```
void DisplayControl(void *pvParameters)
{ (void) pvParameters;
TM1637Display Airdisplay(45, 43);
TM1637Display Skindisplay(51, 53);
TM1637Display Humdisplay(49, 47);
const uint8_t SEG_init[] = {
            SEG_G,
            SEG_G,
            SEG_G,
            SEG_G
                        };
byte SetLed = 23;
byte ActualLed = 24;
byte SkinLed  = 25;
pinMode(SetLed, OUTPUT);
pinMode(ActualLed, OUTPUT);
pinMode(SkinLed, OUTPUT);
digitalWrite(SetLed, LOW);
digitalWrite(ActualLed, LOW);
digitalWrite(SkinLed, LOW);
```

```
while (1) {
if (!setStatus) {
Serial.println("Normal Operation!");
if (!Air_Skin) {
digitalWrite(SkinLed, HIGH);
}
else {
digitalWrite(SkinLed, LOW);
}
if (toggleStatus) {
digitalWrite(SetLed, HIGH);
digitalWrite(ActualLed, LOW);
Airdisplay.setBrightness(7, true);
Airdisplay.showNumberDecEx(SetAirTemp * 100, 0x40, true);
Skindisplay.setBrightness(7, true);
Skindisplay.showNumberDecEx(SetSkinTemp * 100, 0x40, true);
Humdisplay.setBrightness(7, true);
Humdisplay.showNumberDec(SetHumidity);
}
else if (!toggleStatus) {
digitalWrite(SetLed, LOW);
digitalWrite(ActualLed, HIGH);
Airdisplay.setBrightness(7, true);
Airdisplay.showNumberDecEx(AirTemp * 100, 0x40, true);
Skindisplay.setBrightness(7, true);
Skindisplay.showNumberDecEx(SkinTemp * 100, 0x40, true);
Humdisplay.setBrightness(7, true);
Humdisplay.showNumberDec(HumidityValue);
}
}
else if (setStatus) {
Serial.println("User Menu!");
digitalWrite(SetLed, HIGH);
digitalWrite(ActualLed, LOW);
Airdisplay.setBrightness(7, true);
Airdisplay.showNumberDecEx(newSetAirTemp * 100, 0x40, true);
Skindisplay.setBrightness(7, true);
Skindisplay.showNumberDecEx(newSetSkinTemp * 100, 0x40, true);
Humdisplay.setBrightness(7, true);
Humdisplay.showNumberDec(newSetHum);
if (humBtnStatus) {
Serial.println("IN Humidity Menu!");
```

```
bool up =  digitalRead(upBtn);
bool down =  digitalRead(downBtn);
bool enter = digitalRead(enterBtn);
Serial.print("NEW SET HUMIDITY:::");Serial.println(newSetHum);
if (!up && newSetHum < 95) {
newSetHum += 1;
manuPeriod = millis();
               }
else if (!down && newSetHum > 20) {
newSetHum -= 1;
manuPeriod = millis();
   }
else if (!enter) {
SetHumidity = newSetHum;
               manuPeriod = millis();
       }
                }
else if (AirBtnStatus) {
Serial.println("IN Air Temperature Menu!");
bool up =  digitalRead(upBtn);
bool down =  digitalRead(downBtn);
bool enter = digitalRead(enterBtn);
Serial.print("NEW SET AIR TEMPERATURE:::");Serial.println(newSetAirTemp);
if (!up && newSetAirTemp < 39) {
newSetAirTemp += 0.1; manuPeriod = millis(); H_MarginError = false;
T_MarginError = false;
   }
else if (!down && newSetAirTemp > 28) {
newSetAirTemp -= 0.1; manuPeriod = millis(); H_MarginError = false;
T_MarginError = false;
      }
else if (!enter) {
SetAirTemp = newSetAirTemp; manuPeriod = millis();
H_MarginError = false;Air_Skin=true;
T_MarginError = false;
            }
                 }
else if (SkinBtnStatus) {
Serial.println("IN Skin Temperature Menu!");
bool up =  digitalRead(upBtn);
bool down =  digitalRead(downBtn);
bool enter = digitalRead(enterBtn);
```

```
Serial.print("NEW SET SKIN TEMPERATURE:::");Serial.println(newSetSkinTemp);
if (!up && newSetSkinTemp < 39) {
newSetSkinTemp += 0.1; manuPeriod = millis(); H_MarginError = false;
T_MarginError = false;
      }
else if (!down && newSetSkinTemp > 28) {
newSetSkinTemp -= 0.1; manuPeriod = millis(); H_MarginError = false;
T_MarginError = false;
   }
else if (!enter) {
SetSkinTemp = newSetSkinTemp; manuPeriod = millis(); counter = 0;
H_MarginError = false;Air_Skin=false;
T_MarginError = false;
 }
   }
      }
        }
          }
```

## Error Module

```
void Error(void *pvParameters) {
(void) pvParameters;
byte WaterErroeLed = 26;
byte AirErrorLed = 27;
byte SkinErrorLed = 28;
byte HumidityErrorLed = 29;
byte H_HighLed = 30;
byte AirHighLed = 31;
byte AirLowLed = 32;
byte WaterlevelPin = 9;
byte Skin_LH_Led = 33;
byte HumidityErrorMargin = 15;
float TempErrorMargin = 2;
byte ErrBuzzer = 22;
pinMode(WaterErroeLed, OUTPUT);
pinMode(AirErrorLed, OUTPUT);
pinMode(SkinErrorLed, OUTPUT);
pinMode(HumidityErrorLed, OUTPUT);
pinMode(H_HighLed, OUTPUT);
pinMode(AirHighLed, OUTPUT);
pinMode(AirLowLed, OUTPUT);
pinMode(Skin_LH_Led, OUTPUT);
```

```
pinMode(ErrBuzzer, OUTPUT);
pinMode(WaterlevelPin, INPUT);
digitalWrite(ErrBuzzer, LOW);
while (1) {
boolean WaterLevel = digitalRead(WaterlevelPin);
if (WaterLevel) {
digitalWrite(WaterErroeLed, HIGH);
Serial.println("WATER LEVEL LOW");
vTaskDelay( 250 / portTICK_PERIOD_MS );
BuzzerLOW(ErrBuzzer);
}
else {
digitalWrite(WaterErroeLed, LOW);
   }
if (!AirStatus) {
digitalWrite(AirErrorLed, HIGH);
Serial.println("AIR SENSOR FAILED!");
vTaskDelay( 250 / portTICK_PERIOD_MS );
BuzzerHIGH(ErrBuzzer);
  }
   else {
digitalWrite(AirErrorLed, LOW);
if (T_MarginError && Air_Skin) {
if (AirTemp > (SetAirTemp + TempErrorMargin)) {
digitalWrite(AirHighLed, HIGH);
digitalWrite(AirLowLed, LOW);
BuzzerHIGH(ErrBuzzer);
vTaskDelay( 250 / portTICK_PERIOD_MS );
      }
else if (AirTemp < (SetAirTemp - TempErrorMargin)) {
digitalWrite(AirLowLed, HIGH);
digitalWrite(AirHighLed, LOW);
BuzzerHIGH(ErrBuzzer);
      }
else {
digitalWrite(AirLowLed, LOW);
digitalWrite(AirHighLed, LOW);
      }
    }
   }
if (!SkinStatus) {
digitalWrite(SkinErrorLed, HIGH);
```

```
vTaskDelay( 250 / portTICK_PERIOD_MS );
Serial.println("SKIN Sensor Failed!");
 }
else {
digitalWrite(SkinErrorLed, LOW);
if (T_MarginError && !Air_Skin) {
if (SkinTemp > (SetSkinTemp + TempErrorMargin) || SkinTemp <
(SetSkinTemp - TempErrorMargin)) {
digitalWrite(Skin_LH_Led, HIGH);
BuzzerHIGH(ErrBuzzer);
vTaskDelay( 250 / portTICK_PERIOD_MS );
       }
 else {
 digitalWrite(Skin_LH_Led, LOW);
       }
     }
   }
 if (!StatusHumidity) {
 digitalWrite(HumidityErrorLed, HIGH);
 Serial.println("Humidity Sensor Not found!");
 vTaskDelay( 250 / portTICK_PERIOD_MS );
 BuzzerHIGH(ErrBuzzer);
   }
 else {
 digitalWrite(HumidityErrorLed, LOW);
 if (H_MarginError) {
 if ((HumidityValue > (SetHumidity + HumidityErrorMargin))
|| (HumidityValue < (SetHumidity - HumidityErrorMargin))) {
digitalWrite(H_HighLed, HIGH);
vTaskDelay( 250 / portTICK_PERIOD_MS );
BuzzerLOW(ErrBuzzer);
   }
else {
digitalWrite(H_HighLed, LOW);
  }
     }
        }
          }
           }
void BuzzerHIGH(byte pin) {
if (!muteStatus){
digitalWrite(pin, HIGH);
```

```
vTaskDelay( 1200 / portTICK_PERIOD_MS );
digitalWrite(pin, LOW);
vTaskDelay( 400 / portTICK_PERIOD_MS );
    }
  }
void BuzzerLOW(byte pin) {
if (!muteStatus){
digitalWrite(pin, HIGH);
vTaskDelay( 400 / portTICK_PERIOD_MS );
digitalWrite(pin, LOW);
vTaskDelay( 400 / portTICK_PERIOD_MS );
   }
}
```

## PID Controller

```
void PIDController(void *pvParameters) {
(void) pvParameters;
unsigned long lastTime, lastTime1;
double OutputTemp = 0;
double errSumTemp = 0, lastErrTemp = 0;
double OutputHum = 0;
double errSumHum = 0, lastErrHum = 0;
double kp = 800, ki =20, kd = 120;
double interval = 400;
boolean stateTemp = false;
boolean stateHum = false;
long nowOffTimeTemp = 0;
unsigned int DelayOffTemp = 0;
long nowOffTimeHum = 0;
unsigned int DelayOffHum = 0;
int maxRange = 3500;
int maxRangetemp = 5000;
int minRange = 0;
byte Heater = 13;
byte Heater1 = 12;
byte mistControl = 10;
pinMode(Heater, OUTPUT);
pinMode(Heater1, OUTPUT);
pinMode(mistControl, OUTPUT);
digitalWrite(Heater, HIGH);
digitalWrite(Heater1, HIGH);
```

```
digitalWrite(mistControl, HIGH);
while (1)
{
if (AirStatus) {
unsigned long now = millis();
int minRangetemp = 1200;
double timeChange = (double)(now - lastTime);
double error = 0;
if (timeChange > interval)
{
if (Air_Skin) {
error = SetAirTemp - AirTemp;
}
else if (!SkinStatus) {
return;
}
if (OutputTemp != maxRange && OutputTemp != minRangetemp)
{
errSumTemp += error;
}
double dErr = (error - lastErrTemp);
OutputTemp = kp * error + ki * errSumTemp + kd * dErr;
if (OutputTemp > maxRange)
{
OutputTemp = maxRange;
}
else if (OutputTemp < minRangetemp) {
OutputTemp = minRangetemp;
}
lastErrTemp = error;
lastTime = now;
}
//Serial.println(OutputTemp);
DelayOffTemp = ((maxRangetemp) - OutputTemp) ;
if (millis() - nowOffTimeTemp > DelayOffTemp)
{
stateTemp = 1;
if (millis() - nowOffTimeTemp > maxRangetemp) {
stateTemp = 0;
nowOffTimeTemp  = millis();
}
}
```

```
if (stateTemp) {
digitalWrite(Heater, LOW);
        }
else if (!stateTemp) {
digitalWrite(Heater, HIGH);
            }
               }
else if (!AirStatus){ digitalWrite(Heater, HIGH);}
if (StatusHumidity) {
unsigned long now1 = millis();
double timeChange1 = (double)(now1 - lastTime1);
double error1 = 0;
if (timeChange1 > interval)
   {
error1 = SetHumidity - HumidityValue;
if (OutputHum != maxRange && OutputHum != minRange) {
errSumHum += error1;
          }
double dErr1 = (error1 - lastErrHum);
OutputHum = kp * error1 + ki * errSumHum + kd * dErr1;
if (OutputHum > maxRange) {
OutputHum = maxRange;
            }
else if (OutputHum < minRange) {
OutputHum = minRange;
           }
lastErrHum = error1;
lastTime1 = now1;
            }
DelayOffHum = (maxRange - OutputHum);
 if (millis() - nowOffTimeHum > DelayOffHum)
         {
stateHum = 1;
if (millis() - nowOffTimeHum > maxRange) {
stateHum = 0; nowOffTimeHum = millis();
nowOffTimeHum  = millis();
            }
                 }
if (stateHum) {
digitalWrite(mistControl, LOW);
                 }
else if (!stateHum) {
```

```
digitalWrite(mistControl, HIGH);
     }
             }
else if (!StatusHumidity){digitalWrite(mistControl, HIGH);}
                 }
                         }
```

## GET HUMIDITY

```
double GetHumidity(int pin,float actualTemp,bool& StatusHumid){
double sensorValue = analogRead(A0);
double TrueRH =0;
float Vout = sensorValue * (5.0 / 1023.0);
if (sensorValue < 20){StatusHumid = false; return 0;}
else if (sensorValue > 20){StatusHumid = true;}
double sensorRH = double(double(Vout*0.2)-0.1515);
sensorRH = double(sensorRH/0.00636);
if (actualTemp > 0){
double TrueRH = (sensorRH)/(1.0546-double(0.00216*actualTemp));
TrueRH = round(TrueRH);
return TrueRH;
}
  else{
return round(sensorRH);;
   }
    }
```

## GET TEMPERATURE

```
void GetTemperature(OneWire Object,boolean& ComStatus,float& value){
byte present = 0;
byte data[12];
byte addr[8];
ComStatus = true;
Object.reset_search();
if ( !Object.search(addr)) {
Object.reset_search();
ComStatus = false;
value = 0;
return;
 }
 Object.reset();
 Object.select(addr);
```

```
Object.write(0x44, 1);
//delay(1000);
vTaskDelay( 1000 / portTICK_PERIOD_MS );
present = Object.reset();
Object.select(addr);
Object.write(0xBE);
int i = 0;
for ( i = 0; i < 9; i++) {
data[i] = Object.read();
}
int16_t raw = (data[1] << 8) | data[0];
value = (float)raw / 16.0;
}
```

## GET SENSOR

```
void GetSensor(void *pvParameters){
(void) pvParameters;
while(1){
GetTemperature(AirTemp_object,AirStatus,AirTemp);
vTaskDelay( 250 / portTICK_PERIOD_MS );
GetTemperature(SkinTemp_object,SkinStatus,SkinTemp);
vTaskDelay( 250 / portTICK_PERIOD_MS );
HumidityValue = GetHumidity(HumidityPin,AirTemp,StatusHumidity);
vTaskDelay( 250 / portTICK_PERIOD_MS );
  }          }
```

## IOT APPLICATION

```
void WiFiControl(void *pvParameters) {
(void) pvParameters;
String AP = "PTCL-BB";      // AP NAME
String PASS = "12341234"; // AP PASSWORD
String API = "1TKXFSLCNUNDRLBA";   // Write API KEY
String HOST = "api.thingspeak.com";
String PORT = "80";
vTaskDelay( 5000 / portTICK_PERIOD_MS );
sendCommand("AT", 5, "OK");
sendCommand("AT+CWMODE=1", 5, "OK");
```

```
sendCommand("AT+CWJAP=\"" + AP + "\",\"" + PASS + "\"", 20,        "OK");
while (1) {
String getData = "GET /update?api_key=" + API +
"&field1="+AirTemp+"&field2="+SkinTemp+"&field3="+HumidityValue;
sendCommand("AT+CIPMUX=1", 5, "OK");
sendCommand("AT+CIPSTART=0,\"TCP\",\"" + HOST + "\"," +PORT, 15, "OK");
sendCommand("AT+CIPSEND=0," + String(getData.length() + 4), 4, ">");
Serial1.println(getData); vTaskDelay( 1500 / portTICK_PERIOD_MS ); countTrueCommand++;
sendCommand("AT+CIPCLOSE=0", 5, "OK");
Serial.println("Sending Wifi Data!");
}

    }
void sendCommand(String command, int maxTime, char readReplay[]) {
//Serial.print(countTrueCommand);
// Serial.print(". at command => ");
//Serial.print(command);
//Serial.print(" ");
while (countTimeCommand < (maxTime * 1))
      {
Serial1.println(command);//at+cipsend
if (Serial1.find(readReplay)) //ok
        {
found = true;
break;
             }
countTimeCommand++;
          }
if (found == true)
        {
 //Serial.println("OYI");
 countTrueCommand++;
  countTimeCommand = 0;
         }
  if (found == false)
           {
   //Serial.println("Fail"); countTrueCommand = 0;
    countTimeCommand = 0;
             }
     found = false;              }
```

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# Design and Development of Infant Incubator

*by* Yasir Ilyas

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