Design and Development of an Infant Incubator for Controlling Multiple Parameters

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ABSTRACT: **The preterm infant care is one of the most important, delegate and sensitive area in the Bio-medical field. Some new-born's are at a higher risk of mortality and are called high risk infants, because the gestational age or their birth weight put them at a higher-than-average risk of disease and death. Since most infants hospitalized in NICU are born preterm, the problems of high risk infants are mainly related to prematurity. Thirty eight percent of mortalities in the first 5 years of age belong to prenatal period and out of these, 28% is related to preterm birth. The results of statistics in Iran show that in 1980, 13% of new-born were preterm, while in 2006 more than 30% of births were preterm [3]. Preterm baby requires surrounding exactly similar as in the womb to cope with the external environment. Perhaps the most important conclusion from recent research into the effects of the physical environment on preterm infants is that each infant should have a 'microenvironment', which can be individualized to needs that are specific to that child's gestational age and medical condition. To some extent, the incubator can serve as this microenvironment, controlling light, sound, smell and protecting from infection [3][5]. An infant incubator provides stable levels of temperature, relative humidity, light condition and oxygen level up to an extent in which the preterm have same condition as in the womb. Air temperature has to be maintained around 35ºC [1]. The purpose of this project is to design and implement a closed loop control system to regulate the temperature, humidity, light intensity by using LED's to avoid jaundice condition and the proper amount of oxygen level inside a neonatal incubator [2]. Microcontroller and PID controller will be used for implementing the hardware. The closed loop control system is a combination of sensors and actuators that operates synchronously to provide a stable thermal environment inside the incubator [3].**

Keywords: Incubator, Temperature, Humidity, Oxygen, Light, LED, Microcontroller, PID Controller.

I. INTRODUCTION

Infants who born before 37 weeks of the gestation period are known as preterm or premature babies. Preterm baby requires surrounding exactly similar as in the womb to cope with the external environment. In fact mammals have the advantage of being homoeothermic, i.e. they have a nearly uniform body temperature, regulated independent of the environmental temperature. 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 and oxygen level. 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 new-born has little ability to conserve heat by changing posture and no ability to adjust their own clothing in a response to thermal stress. Responses may also be hindered by illness or adverse conditions such as hypoxia (below normal levels of oxygen). To provide the similar environment as in the womb infants have to be kept in a device known as incubator. An infant incubator is a device consisting of a rigid box-like enclosure in which an infant may be kept in a controlled environment for medical care. An infant incubator provides stable levels of temperature, relative humidity and oxygen concentration [28]. Air temperature has to be maintained around 37ºC. The relative humidity should follow set values according to the number of incubation days [18].

II. INCUBATOR

The first official neonatal intensive-care unit (NICU) for neonates was established in 1961 at Vanderbilt University. Incubator is a device in which premature or unusually small babies are placed and which provides a controlled and protective environment for their care [4]. Every year, about 1 million infants in the developing world die due to heat loss and dehydration that can be prevented by an intensive care unit i.e. incubators[3]. Thus incubators provides congenial atmosphere for the infants, which helps in thermoregulation. The incubator is considered as an air conditioned room with special specification which we can be control with respect to the condition of baby in incubator. Incubators are designed to provide an optimal environment for new born babies with growth problems (premature baby) or with illness problems [4]. The incubator is an isolated area environment with no dust, bacteria, and has the ability to control temperature, humidity, and oxygen to remain them in acceptable levels. Incubator is designed to keep baby warm, to monitor many of their vital body functions like heart rate, blood pressure, oxygen saturation and to support their breathing if necessary. Regarding the temperature and humidity control, incubators should minimize heat loss from the neonate and eddies around him/her. The main physical variables affecting the incubator environment are temperature, humidity, oxygen saturation and light.

III. PARAMETERS AFFECTING THE INCUBATORS

3.1 TEMPERATURE

The infants have very low thermal regulation and temperature regulation is one of the most important factors which affect the preterm. One of the major problems that new-born's face is improper thermoregulation. The temperature inside the mother's womb is 38ºC (100.4ºF). Leaving the warmth of the womb at birth, the wet new born finds itself in a much colder environment and immediately starts losing heat. If heat loss is not prevented and is allowed to continue, the baby will develop hypothermia and is at increased risk of developing health problems and of death [6]. Avoiding hypothermia (rectal temperature less than 36.5°C or 96.8° F) is important for new-born health outcomes because hypothermia increases morbidity and mortality. A baby can lose one degree of body temperature per minute when wet, even in a room that is not obviously cold. To prevent heat loss, it is necessary to dry up the baby and wrap the baby in a clean, dry cloth and to make sure the baby's head is covered (WHO, 1977).

3.2HUMIDITY

Low relative humidity of a servo controlled incubator increases the temperature of the incubator itself and the oxygen consumption of premature infants accordingly. This causes an increase in the insensible water losses. In addition, premature infants with small weight or illnesses are susceptible to unfavorable incidents such as apneic spells. However, insensible water losses under radiant warmers are higher than conventional incubators. Apparently, small variations in relative humidity inside incubators with skin servo control do not influence the insensible water loss; however significant fluctuations in relative humidity would vary the amount of insensible water losses. Few investigations have shown that the body weight and insensible water loss is inversely proportional to the water loss. The humidity of the shell environment can negatively affect the patient if it is not at a healthy level. Infants can lose moisture and heat by evaporation if humidity is too low, while higher levels of humidity increase the likelihood for germs and bacteria to be present. The ability to control or at least monitor humidity is beneficial [4].

3.3 LIGHT

The physical environments of hospitals are critical to good patient care. High light levels (e.g. phototherapy) the lack of regular light/dark cycles may also adversely affect new-born patients. The level of ambient light should be flexible to allow day-night cycling [5]. The technique to control the jaundice in the neonates is also comprises of light therapy. Phototherapy is the best solution to control the jaundice in the premature babies placed in baby incubators. Babies with jaundice will usually receive the treatment of phototherapy for 4 to 7 days. When ill infants with low birth weight receive phototherapy in incubators, their insensible water losses are significantly doubled or tripled. This is attributed to the heat source placed inside the incubator for the purpose of phototherapy. It may also be attributed to the delay in time until the effectiveness of phototherapeutic processes is reached. In a radiant heat warmer, the exposure to non-ionizing radiant energy causes several changes in infants who required phototherapy (such as, changes in body temperature, higher insensible water loss and fluid intakes) [6]. Although it can be necessary to use radiant heat warmer to nurse premature infants with low birth weight instead of incubators, this causes an increase of insensible water losses. Thus, the smaller the infant (small body weight) the higher the insensible water losses and the fluid intakes accordingly.

3.4 OXYGENATION

Oxygenation is a therapeutic process in which oxygen is administered directly to facilitate breathing. If a baby born more than two months early, her breathing difficulties can cause serious health problems because other immature organs in her body may not get enough oxygen. Ventilation is necessary to provide the patient with fresh air and sufficient oxygen. Flowing air is also necessary to provide sufficient transfer of heat from the heat source to the shell environment and the patient. The ventilation needs to be carefully managed so that there is enough fresh air and convective heat transfer over the heat exchanger, but the flow is not so fast that it makes the patient uncomfortable and causes an increase in heat loss of the incubation system to the outside environment [26]. Incubator oxygen treatments have been used to prevent new-born respiratory distress. The oxygen concentration of inhalation is fixed at a rather high level to improve the distress and the anoxia, while the arterial oxygen partial pressure PaO2 of new-born infants sometimes becomes extremely high and brings about retrolental fibroplasia in the worst case. It is hence desired that the oxygen pressure of inspired gas in an incubator should be adjusted adequately in accordance with the monitored PaO2 output [31].

The block diagram of the project is shown in Fig.1. It mainly consists of the temperature sensor, humidity sensor, light sensor, carbon di-oxide sensor, PID controller and Microcontroller.

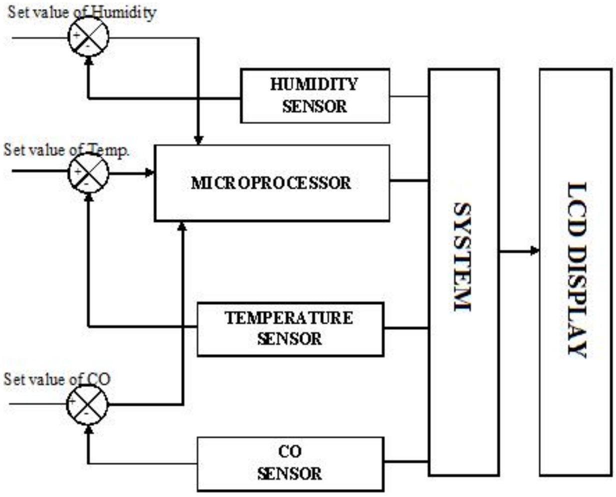


Fig1. Block Diagram of the Hardware

IV. DESIGN COMPONENTS

4.1 TEMPERATURE SENSOR DS18B20

The DS18B20 Digital thermometer provides 9 to 12–bit centigrade temperature measurements and has an alarm function with non-volatile user-programmable upper and lower trigger points as shown in Fig.2. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. It has an operating temperature range of –55°C to +125°C and is accurate to ±0.5°C over the range of –10°C to +85°C. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply [6]. The core functionality of the DS18B20 is its direct-to-digital temperature sensor. The resolution of the temperature sensor is user-configurable to 9, 10, 11, or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C, respectively. The default resolution at power-up is 12-bit. The DS18B20 powers up in a low-power idle state. To initiate a temperature measurement and A-to-D conversion, the master must issue a Convert T command. Following the conversion, the resulting thermal data is stored in the 2-byte temperature register in the scratch pad memory and the DS18B20 returns to its idle state. If the DS18B20 is powered by an external supply, the master can issue "read time slots" (see the 1-Wire Bus System section) after the Convert T command and the DS18B20 will respond by transmitting 0 while the temperature conversion is in progress and 1 when the conversion is done. If the DS18B20 is powered with parasite power, this notification technique cannot be used since the bus must be pulled high by a strong pull up during the entire temperature conversion.

The DS18B20 output temperature data is calibrated in degrees Celsius and for Fahrenheit applications, a lookup table or conversion routine must be used. The temperature data is stored as a 16-bit sign-extended two's complement number in the temperature register. For designing our incubator we have used temperature sensor DS18B20, which is then interfaced with microcontroller (ARDUINO MEGA 2560). The interfacing of both temperature and humidity sensor with microcontroller is shown in fig. 2

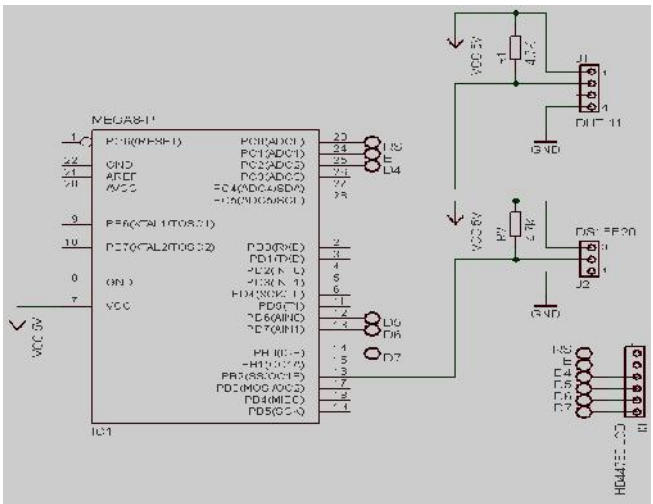


Fig. 2 Interfacing of DS18B20 and DHT-11 with Microcontroller

4.2 HUMIDITY SENSOR

Humidity sensor should provide humidity level in the incubator in terms of relative humidity (%RH) in the range of 0-100%RH. The humidity sensor chosen for the present work is DHT11. Application of a dedicated digital modules collection technology and the temperature and humidity sensing technology, to ensure that the product has high reliability and excellent long-term stability. The sensor includes a resistive sense of wet components and an NTC temperature measurement device, and connected with a high-performance 8-bit microcontroller [8]. DHT11 uses a simplified single-bus communication. Single bus that only one data line, the system of data exchange, control by a single bus to complete. Device (master or slave) through an open drain or tri-state port connected to the data line to allow the device does not send data to release the bus, while other devices use the bus, single bus usually require an external one about 5.1kΩ pull-up resistor, so that when the bus is idle, its status is high. Because they are the master-slave structure, and only when the host calls the slave, the slave can answer, the host access devices must strictly follow the single-bus sequence, if the chaotic sequence, the device will not respond to the host. Its connection diagram with microcontroller ATMEGA 2560 is also shown in fig.2.

4.3 LIGHT SENSOR

Light Dependent Resistor (LDR) is used for detecting the intensity of light in the incubator. For controlling the jaundice in infants the LED PT series will be used. It delivers a blue light with the peak intensity of 455nm. The light is free of unwanted UV and IR radiations. LED maintains the intensity of light level for 20,000 hrs. In this project we have made the array of LED. LED's are opto-semiconductors that convert electrical energy into light energy. LED's offer the advantages of low cost and a long service life compared to laser diodes. LED's are broadly grouped into visible LED's and invisible LED's. Visible LED's are mainly used for display or illumination, where LED's are used individually without photo sensors. Invisible LED's are mainly used with photo sensors such as photodiodes or CMOS image sensors. In the category of visible LED, red LED's are used in combination with photo sensors for applications such as optical switches. These red LED's have high emission power that allows photo sensors to generate a large photocurrent. In the category of invisible LED infrared LED's are also available. These red LED's and infrared LED's are used in a wide range of applications including optical switches, optical communications, analysis and CMOS image sensor lighting. Advances in crystal growth technology and wafer process technology led to develop high-output, long-life LED's (operable for ten years or longer under the optimal drive conditions).

4.4 CARBON MONO-OXIDE SENSOR (MQ-7)

MQ-7 sensor is mainly used to determine the Carbon monoxide gas detection [9]. As the concentration of both carbon di oxide and carbon mono oxide are same, so we can use CO sensor as well to measure the CO2 gas. The cost of CO sensor is really low as compared to that of CO2 sensor and while designing a low cost infant incubator the cost parameter plays a major role.

Measurement of gas pollutants in atmosphere is always a challenging job due to the accuracy required in its measurement. The unprecedented growth in modern technologies and the continued development of industrialization has made the issue of environmental pollution increasingly Carbon monoxide serious and alarming. Among the various gas sensors available in the market, semiconductor sensors are considered to have fast response, high stability, low dependency on humidity, low cost, long life, low power consumption, and small size etc. The semiconductor sensor consists of one or more metal oxides such as tin oxide, aluminum oxide etc. MQ-7 is the semiconductor sensor mainly used to detect Carbon monoxide gas at the ambient atmosphere by using its sensing layer which is consisted of aluminum oxide. When heated to a high temperature an N type semiconducting material decreases its resistance while P type increases its resistance in the presence of a reducing gas. Therefore, a semiconductor sensor produces a strong signal at high gas concentrations. MQ-7 is also produce a strong signal so that it can detect CO from any of the ambient atmospheres which contain Carbon monoxide gas in hazardous level. Its circuit diagram is shown in Fig 3 and interfacing of MQ-7 sensor with microcontroller AT-mega 2560 is shown in Fig.4.

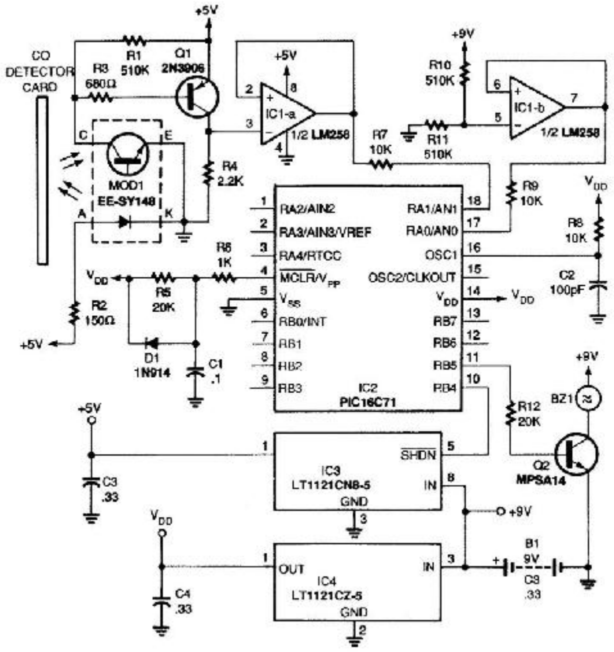


Fig 3 Circuit Diagram of Carbon Monoxide (MQ-7) Sensor

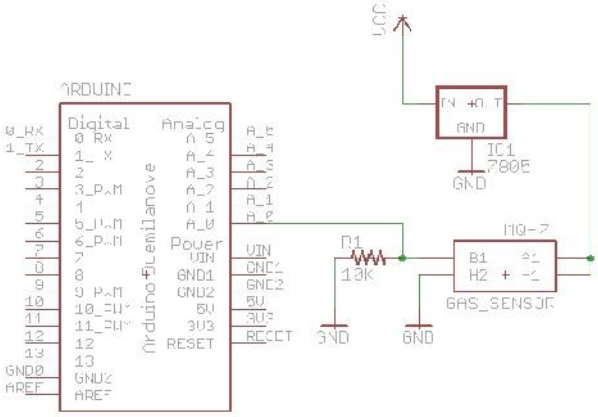


Fig 4 Interfacing of MQ-7 with Microcontroller

4.5 MICROCONTROLLER

The microcontroller used is Arduino mega2560. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet). It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila. The Arduino Mega2560 can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the GND and VIN pin headers of the POWER connector. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The AT Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter. The ATmega2560 has 256 KB of flash memory for storing code, 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library). The ATMega2560 has 16 analog inputs, each of which provides 10 bits of resolution (i.e. 1024 different values).They measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and Analog Reference function. It controls the operation of sensors and gives the output through LCD display as shown in the circuitry shown in Fig5.

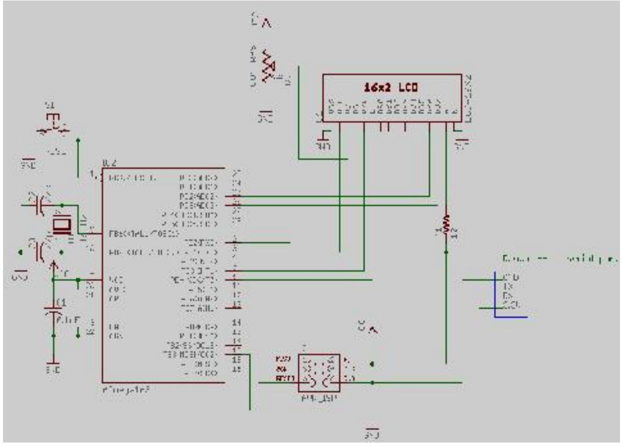


Fig5. Interfacing of Arduino 2560 with LCD

V. RESULT

5.1 Variation of Incubator's temperature with respect to Time

Using DS18B20 we found that the time response is really fast as 1±1 sec (We have put a delay of 1 sec in a complete loop to match the LCD responses). If we increase the delay of the loop more than 1 sec, there will be a garbage value. In Table 5.1, we have given the change in temperature with respect to time by the study of temperature sensor DS18B20.

Table 1 Time vs Incubator Temperature

Time (seconds)	Incubator Temperature (°C)
0	33.25
5	33.48
10	33.86
15	34.13
20	34.19
25	34.25
30	34.31
35	34.38
40	34.46
45	34.54
50	34.61
55	34.7
60	34.81
65	34.88
70	35
75	35.5
80	35.2

In Table 1, we had given the temperature change with respect to time by the study of temperature sensor DS18B20. The maximum temperature range set for the infant in this incubator is 35°C. Initially when incubator is turned ON then the initial temperature is found to be at 33.75°C. As the time increases different values of temperatures have been recorded. As a result we have seen that due to the heat produced by the bulb, the temperature gradually increase and attains the set value i.e. 35°C. Now if the temperature of the incubator increases more than 35°C temperature sensor will sense it and turn ON the Fan which in turn cools it down to the given temperature. The graph between time and temperature of incubator, obtained by the results is shown in Fig.6.

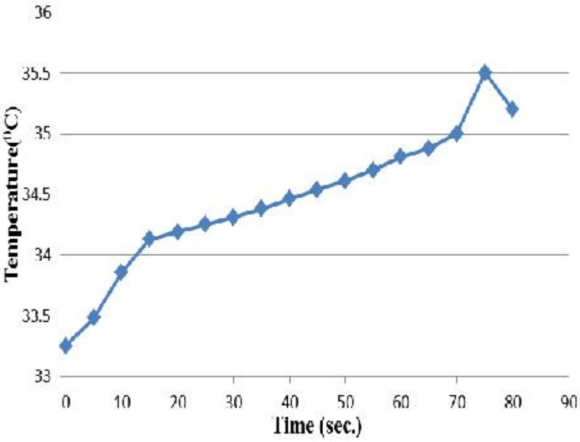


Fig 6 Time vs. Incubator Temperature graph

5.2 Relative Humidity Achieved by the System

Relative humidity, an important factor in designing of an incubator to control thermal loss in an infant, is controlled by the heater of the water reservoir. The temperature which is used to heat the water inside the incubator depends on the maximum-minimum value of relative humidity required in the chamber. Humidity can also be increased and decreased by using water content in the air. Some observations are shown in the table 5.2 for the different values of relative humidity with respect to water temperature.

Table 2 Relative Humidity vs. Water Temperature

Temperature of water (°C)	Relative Humidity (%RH)
33.25	17
33.48	18.45
33.86	21.8
34.13	23.54
34.19	25.98
34.25	27.6
34.38	32.4
34.81	38.32
35	43.54
35.56	47.67

DHT11 sensor is used to study the change in relative humidity with respect to change in water temperature. Our aim is to achieve minimum amount of relative humidity which is 85%RH for a neonate. The starting value of humidity is found to be 66.81%RH at an initial temperature of 33.75°C and the final value obtained is 84.89%RH at a temperature of 35°C. The graph between the water temperature and relative humidity obtained in this project is shown is Fig.7.

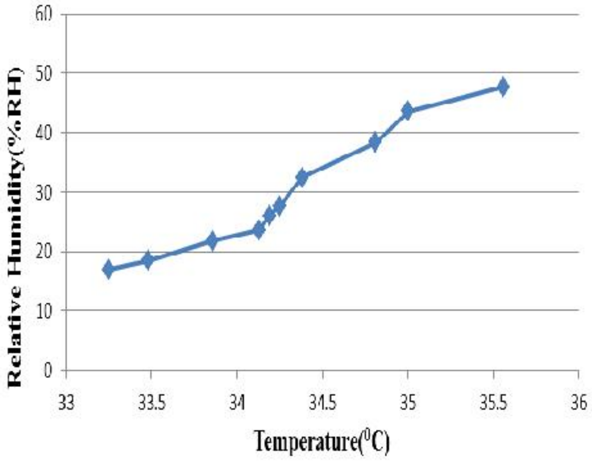


Fig7. Relative Humidity vs Water Temperature graph

5.3 RESULT OF LED

Phototherapy should be started immediately if a rapidly rising bilirubin is expected and with jaundice at less than 24 hours. Light-emitting diode (LED) light source phototherapy is effective in bringing down levels of serum total bilirubin at rates that are similar to phototherapy with conventional (compact fluorescent lamp (CFL) or halogen) light sources. According to level of disease detecting by the doctor’s diagnosis we can manually change (increase or decrease) the intensity of light using potentiometer. Potentiometer controls the current passing through the LED’s which in turn results the change in intensity of LED shown in Fig.8. The light can be applied with overhead lamps, which means that the baby's eyes need to be covered, or with a device called a Biliblanket, which sits under the baby's clothing close to its skin.

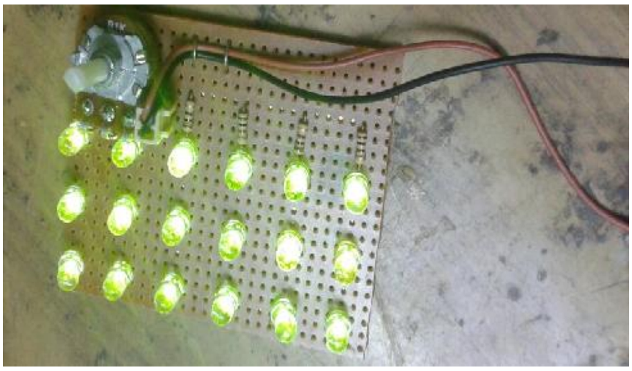


Fig 8 Working of LED’s for Phototherapy

5.4 RESULT OF MQ-7 SENSOR

Sensor resistance varies a logarithmic function of gas concentration, sensitivity characteristics to a certain gas differ with sensor type. When measuring a certain gas, possible interference of co-existing gases must always be taken into consideration. The curve for the variation of CO gas concentration with respect to the sensor resistance is shown in Fig 9 and the concentration of CO_2 is measured by using MQ-7 sensor has been explained in Table 3.

Table 3 Concentration of CO vs Sensor Resistance

Concentration of CO	Sensor resistance
50	1.03
100	1
400	0.5
1000	0.2

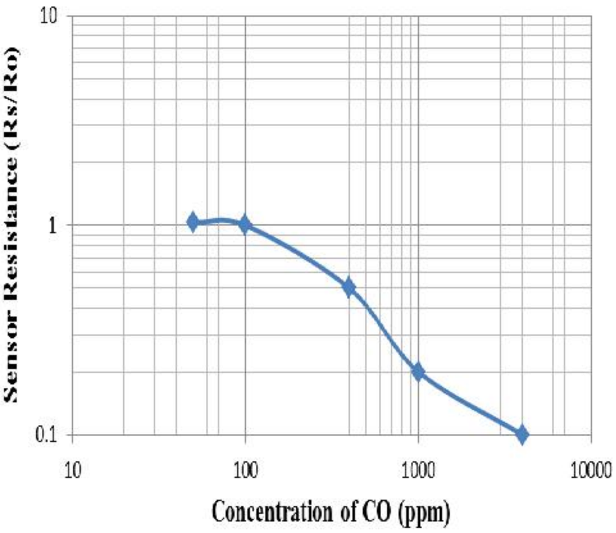
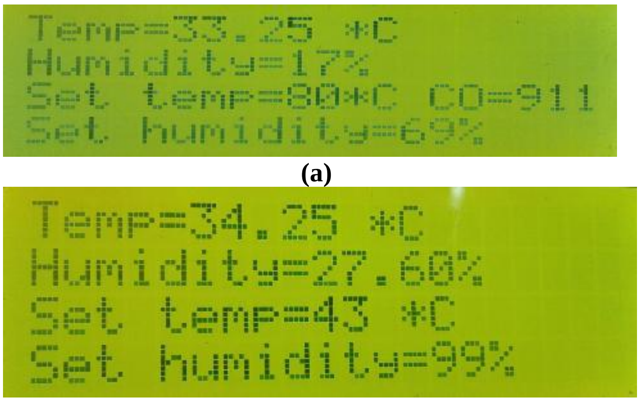


Fig 9. Sensitivity Characteristics of MQ-7 graph

5.5 INCUBATOR IN WORKING CONDITION

After designing the hardware when the project comes in working condition then the different results will be obtained which are shown in the of Fig.10, showing different values for two different time after switching ON the incubator.

In Fig 10 (a) we have seen the values which we are getting at the initial stage after switching ON the incubator. While in Fig 10 (b) we got the values of temperature and humidity after 25 seconds of time.



Temp=33.25 *C
Humidity=17%
Set temp=80*C CO=911
Set humidity=69%

(a)

Temp=34.25 *C
Humidity=27.60%
Set temp=43 *C
Set humidity=99%

(b)

Fig.10 Values for Different parameters: (a) Values at Time = 0 Seconds (b) Values at Time = 25 Seconds.

From above Fig 10 we have seen the difference in temperature as well as humidity with respect to time whose graphs has been shown in Fig.8 and Fig.9 simultaneously.

VI. CONCLUSION

The objective of this project is to design and develop microcontroller and closed loop control system based temperature, humidity, oxygen concentration and light controller for infant incubator. To achieve this hardware is designed so that the above mentioned parameters can be monitored for the normal growth of an infant.

This system can provide optimum automatic control of temperature for the infant using closed loop control system. Moreover it controls the heater of water reservoir according to relative humidity in the infant chamber. The control of relative humidity in chamber is required for making the thermal losses lessen from the infant's body. Also controlling of light will provide proper growth in infant. The controlling of the concentration of gas with the CO sensor is beneficial for infant to protect him from various kinds of breath diseases.

VII. FUTURE SCOPE

Any work, whatsoever precise it may be, has always some scope of improvement. On the same lines the author envisages that there is lot of scope of improvement in the present work. Some of the future aspects of the work in terms of its improvements are the parameters such as pulse measurement can also be introduced for close monitoring and the response of the project can further improved by using the different tuning techniques used for PID controllers. The GSM technique can also be used to reduce the noise created by the alarms in the close monitoring.

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